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DISPOSAL OF SALINE WATER CONVERSION BRINES
--- AN ORIENTATION STUDY

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PREFACE

This project was carried out between December 11, 1956 and April 18, 1957 under Contract No. 14-01-001-92 between the U. S. Department of the Interior, Office of Saline Water and Louis Koenig - Research.

A large number of companies and individuals have freely cooperated in supplying information on details of the diverse technologies encompassed in the report. Most of them are mentioned in the references and the opportunity is taken here to express the author's gratitude to each of them for their help.

In a reconnaissance work of this nature touching on so many technological fields one must expect to find errors of fact, computation or judgement. The author will be grateful for any such errors called to his attention.

Taking the broader view, the purpose of the entire report is to provide an orientation and to stimulate thinking and discussion on the subject of waste disposal for saline water conversion plants. This work therefore should not be looked upon as the final answer on the subject but only the opening statement.

FOREWORD

This is the twentieth of a series of reports designed to present accounts of progress on saline water conversion with the expectation that the exchange of such data will contribute to the long-range development of economical processes applicable to large-scale, low-cost demineralization of sea or other saline water.

Except for minor editing, the data herein are as contained in the final report submitted by Louis Koenig - Research under Contract No. 14-01-001-92 which has been accepted as fulfilling the provisions of that contract. The data and conclusions given in this report are essentially those of the Contractor and are not necessarily endorsed by the Department of the Interior.

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CHAPTER 1

INTRODUCTION

Purposes - Fringe Areas - Ultimate Disposal -
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References

This report constitutes a preliminary exploration of the problem of disposing of waste salts, usually in the form of brine, resulting from the conversion of saline waters to fresh water. So far as known, this is the first attempt that has been made to assay the order of magnitude of these waste disposal costs. As a first attempt the result is definitely intended as a bird's-eye view which will allow selection of favorable areas for more intensive study. The cost estimates are of a "huddle" estimate type, usually a one man huddle. At the same time it was desired to present a general method by which the technical and economic aspects of any particular disposal method could be worked out. For that reason the report contains a number of correlations allowing extrapolation and interpolation which would not ordinarily be found in cost estimating for a specific process or a specific location.

Purposes The purpose of undertaking this study at the present time was to provide an economic as well as a research and engineering guide. Prior to this study the costs of waste disposal for the saline water conversion processes were unknown even in general magnitude. Thus, the various cost estimates for converted water lacked an essential element of total cost which might indeed prove even greater than, in fact much greater than, the cost of conversion itself. Obviously, economic judgments cannot be made except on the basis of total costs.

Secondly, it was not known whether the waste disposal problem in saline water conversion was unique, particularly with regard to magnitude. For example, the conversion of two gallons of water approximating the composition of sea water to one gallon of fresh water calls for the disposal of about half a pound of salts. Supplying the water for a small city of 20,000 would on this basis require the disposal of 75 tons of salt per day. It was not known whether the sheer magnitude of such a disposal problem made disposal unfeasible.

Third, disposal costs and problems can have a direct influence on the guidance of research and engineering in the following way. Costs for the various presently favored processes have been calculated not including disposal costs. Addition of disposal costs will, of course, increase the per thousand gallon cost for all processes. However, it will not increase all equally for some processes produce less waste per unit of product than others. If disposal costs per thousand gallons of waste are quite high then those processes with low ratios of waste to product will be favored.

Finally, the planning of waste disposal measures concurrently with the development of the process constitutes currently recommended good practice in process development.

Fringe Areas The intention of the current study was to list all the methods of disposal for saline water conversion wastes. This of course is not to be taken literally. At any given stage of the art one unbound by technical or economic necessities can always conceive of fantastic solutions. Toward the present problem three actual examples will suffice.

It has been suggested that any waste material can now with the nuclear arts be transmuted into other materials which are useful or less harmful.

The earth satellite provides a handy solution for a number of worldly problems and gives rise to another suggestion that waste materials could be rocketed off into outer space.

Several people have suggested for saline water conversion wastes that they be "incinerated" and dispersed in the air. While this possibility is interesting from the standpoint of providing not only cloud seeding nuclei but also the water to form the clouds it probably can most gracefully be disposed of on the basis of cost and of substituting an air pollution menace for a water pollution menace.

Ideas of the above categories on the fanciful periphery of technology are not harnessed by calculations in this report. Unfortunately the nature of the problem and particularly its projection into the future makes it difficult to state whether some proposed solutions are inside of or outside of this periphery.

Ultimate Disposal Disposal of saline water conversion wastes is a problem quite distinct from the usual problem of waste disposal and is in a category with only a few other types of waste. The majority of waste disposal operations consist of either:

a. converting a waste material into a useful or harmless material and discharging the harmless residues to water bodies or ground water, or

b. withdrawing and concentrating the harmful portion of the waste so that it is more economically amenable to ultimate disposal, and releasing the harmless residue to water bodies or ground water.

Sewage is probably in volume the largest waste disposal operation in the United States. Its disposal involves both of the aspects cited above. Sewage, containing incidentally 997 parts of water for every 3 parts of other materials, is treated so that the obnoxious materials are for the most part changed to inoffensive materials such as CO_2 water and other simple compounds. The irreducible minimum of solids residual from this treatment are in such a small volume that they can be disposed of by segregation and abandonment or even in some cases sold as a useful product, soil conditioner, where their obnoxious properties become useful properties.

Saline water conversion wastes however are in a quite different category along with oil well brines and radioactive wastes. There is no way that they can be reduced to simple harmless compounds because they already are the simplest of inorganic compounds. Secondly, there is almost by definition no good way of separating them from their carrying water so that the water may be reclaimed for if there was such a way it would have been used as a saline water conversion process itself.

Thirdly, the quantities of materials involved are very large. Fourth, the materials are on the lowest rung of the ladder of economic value, for example, sodium chloride, and nothing can be made from them that could not be made cheaper from existing purer deposits of the same material. A single exception to the latter statement will be discussed in one of the subsequent chapters.

Thus we are faced not with a common waste discharge problem but with a problem in ultimate disposal on a scale which has not been approached before. The magnitude of the quantities approach the largest currently handled in oil well brine disposal plants at rather moderate water production capabilities. If saline water conversion plants of moderate size become common in a geographic area the magnitude of the ultimate disposal problem will be much greater than any heretofore encountered. Accordingly some processes must be considered which would seem fantastic judged by present-day waste disposal concepts.

Processes Considered Twelve processes have been considered as in the realm of present interest. These processes are compounded from eight unit operations, five final operations and three intermediate operations. A graphic presentation of the processes and the operations which make them up together with the sequence of those operations is presented in Table 1-1. The unit operations are described and defined as follows:

INJECT: Injecting the wastes into underground strata such that they are confined and never again come in contact with human activity, or if they do so, do it at such a remote date and after so much dilution with other waters that the effect is not noticeable.

LAND DUMP: Depositing the material on land areas which will be forever worthless and not useable in human activity. An example would be the use of land in remote desert playas and sinks where the land is not useable for agriculture or other human purposes and from whence neither surface nor underground drainage finds its way outside.

ABANDON: The same operation as land dumping except that it is carried out at the site of an intermediate operation, specifically evaporation to dryness, and done at the plant site.

SEA DISCHARGE: Disposal in the Gulf, the ocean or existing inland salt water bodies, such as Great Salt Lake. Presumably it will not be necessary to barge the material for deep sea disposal as the salts are in general already found in sea water.

STREAM DISCHARGE: Discharging the waste into flowing streams presumably during times of flood flow when the exceeding of pollution limits may be avoided.

The three intermediate operations which may be utilized prior to the final operations are defined as follows:

TABLE 1 - 1

	UNIT OPERATIONS							
	INTERMEDIATE			FINAL				
PROCESSES	CONVEY	EVAPORATE TO SATN.	EVAPORATE TO DRYNESS	INJECT	ABANDON	LAND DUMP	SEA DISCHARGE	STREAMS
I	X						Y	
II	Y	X					Z	
III	Y		X				Z	
IV	X					Y		
V	Y	X				Z		
VI	Y		X			Z		
VII			X		Y			
VIII				X				
IX		X		Y				
X	X			Y				
XI	Y	X		Z				
XII								X

X, Y, Z order of operation

CONVEY: Carrying liquid or solid material by pipeline, railroad, truck, or other means over considerable distances.

EVAPORATE TO SATURATION: Evaporating the waste, here by solar evaporation, down to the point of saturation, in order to concentrate it.

EVAPORATE TO DRYNESS: Solar evaporation until all the water is removed so that the remaining dry solids may be finally disposed of.

The twelve Processes represent the following combinations of these intermediate and final operations.

Obviously each Process can have but one final operation but it may have one or more intermediate operations. Not all combinations of these operations are shown. Some of them are physically impossible. Others, while physically possible are only trivially different from Processes listed. For example, Process XII consisting of discharging to flooding streams might be followed by a Process XIII which would include conveying followed by discharge to streams. There are no essential differences between the two not quickly illuminated by simple addition.

Process I. Convey the waste to the sea.

Process II. Evaporate to saturation and convey to the sea. This provides for the possibility that conveyance to the sea might be a major cost and therefore an attempt should be made to reduce it by prior evaporation.

Process III. Evaporate to dryness and convey the dry salts to the sea.

Process IV. Convey the waste to a remote land dump, which may be closer than the sea.

Process V. Evaporate to saturation and convey to a land dump.

Process VI. Evaporate to dryness and convey the dry salts to a land dump.

Process VII. Evaporate to dryness and abandon the resulting dry solids in situ.

Process VIII. Inject the waste directly into underground strata.

Process IX. Evaporate the waste to saturation so as to reduce the volume and thus the expense of injection.

Process X. Since the cost of injection wells is considerable it might be cheaper to use abandoned oil wells which in general would involve conveying of the waste to the sites of the abandoned oil wells.

Process XI. Evaporation to reduce the volume and save costs both in conveyance and injection. Evaporation may be even more indicated when it is necessary to convey.

PROCESS XII. Discharge the material to streams in times of flood.

The next few chapters discuss the physical and economic parameters associated with the above unit operations usually to arrive at some cost figure dependent on the selected parameters. The remaining chapters discuss the 12 processes.

Product-to-Waste Ratios for Various Conversion Processes

In considering the economic conclusions reached in the succeeding chapters it is necessary to keep in mind how they apply in the overall cost per thousand gallons of product for saline water conversion. The units chosen to express investment costs are $/gallon/day of capability ($/gpd); production costs, $ per thousand gallons ($/Mg). The volumes of waste chosen for study are 20, 200, and 2,000 Mgd (thousand gallons per day). This represents a reasonable illustrative range for our purposes.

However, both the volumes and the cost figures apply to waste rather than product. If a disposal process has an investment cost of $0.12/gpd and an operating cost of $0.04/Mg then waste disposal adds those figures to the gpd and Mg costs of the conversion process only if that conversion process produces one volume of product for each volume of waste. If the process produces four volumes of product for one of waste then only one quarter of the above figures is added to to the cost of product.

Some workers in the resource field are attempting to educate people, technical and non-technical, to the concept that water is a vendible commodity and that water reclamation or conversion should be thought of as a chemical process of water manufacture. This campaign is having some success but the still greater extent of its failure is evidenced by the scarcity of "yield" data among discussions of saline water conversion and reclamation. A number of papers and reports (including some of the Office of Saline Water series) have been issued containing engineering cost calculations on processes for which the yield of product per gallon feed is nowhere indicated. This of course is one of the most vital figures of interest for any chemical manufacturing process and yet even among engineers and scientists dealing with conversion process the concept still exists that feed water is so cheap that the yield is not of particular importance.

Yet this yield factor expressed as product-to-waste ratio is necessary to a true understanding of the economics of disposal processes. Such information as has been obtained on current saline water processes is listed below:

Process	Product-to-waste ratio	Ref.
Badger-Hickman Centrifugal Evaporation	0.5	(1-1)
Electrical Membranes	4.0	(1-2)
Solvent Extraction	1.0	(1-3)
High Rate Vapor Compression	1.0	(1-4)
Freezing	1.7	(1-5)

REFERENCES

Throughout the report references for each chapter are found at the end of that chapter and are indicated in the text by numbers in parentheses

(1-1) Badger Manufacturing Company: Research on and Development of Badger Hickman Centrifugal Distillation Techniques and Equipments. Saline Water Research and Development Progress Report No. 12, Office of Saline Water, November 1956, 78 pp.

(1-2) Smith, David B. and Richheimer, Charles E.: Cost Estimates Favor Electrodialysis for Treatment of Saline Waters, Civil Engineering 238-241, April 1956. See also Katz, William E.: The Present Status of Electric Membrane Demineralization, Preprint of a paper to be presented before the Engineers Society of Western Pennsylvania, October 24, 1956. (Ditto copy) 22 pp. - which gives a ratio of 5.0.

(1-3) Desalination by Liquid-Liquid Extraction. Texas A&M Research Foundation, Annual Report, Volume 1, Office of Saline Water, Contract No. 14-01-001-60 and 14-01-001-77, July 1, 1956.

(1-4) Bliss, Harding: Forced Circulation and Dropwise Condensation Techniques for Improving Heat Transfer Rates for Vapor Compression Evaporators. Office of Saline Water, Saline Water Research and Development Progress Report No. 8, October, 1955, 22 pp.

(1-5) Hendrickson, Harold M. and Moulton, Ralph W.: Research and Development of Processes for Desalting Water by Freezing. Office of Saline Water, Saline Water Research and Development Progress Report No. 10, August 1956, 164 pp.

CHAPTER 2

SUMMARY

This work reports an investigation of the various processes that might be used for the ultimate disposal of the waste brines resulting from conversion of saline water to fresh water, particularly at the inland sites. The investigation is of a reconnaissance nature designed to show the areas worthy of further detailed attention.

Processes Studied

The major results comprise cost comparisons among twelve disposal processes, compounded out of eight unit operations. The disposal processes considered in this investigation are:

Pipeline the waste to the sea

Solar evaporate the waste to saturation and pipeline to the sea

Solar evaporate completely to dryness and convey by railroad to the sea

Pipeline the waste to a land dump closer than the seacoast

Evaporate to saturation and pipeline to a land dump

Evaporate to dryness and freight to a land dump.

Solar evaporate to dryness and abandon in situ at the plant site.

Inject the waste to underground formations

Solar evaporate to saturation and inject

Pipeline the waste and inject in an abandoned oil well

Evaporate to saturation and pipeline to an abandoned oil well

Discharge the waste to streams in times of flood

Cost Comparisons

The costs of the unit operations are developed over a range of the pertinent parameters chosen to represent the range of those parameters to be expected in practice. Since it was impossible to make comparisons among all permutations and combinations of these unit operations, the process comparisons have for the most part been made for a standardized set of the parameters, chosen to represent the median values of the parameters to be expected in practice. The standard values of the major parameters thus chosen are as follows:

Capability - 2000 Mgd of waste

Distance to the sea - 300 miles

Distance to a closer land dumping area - 50 miles

Evaporation for brine - 40 inches per year

Depth of injection wells - 6000 feet

Casing head pressure for injection - 260 psi

The costs of one set of processes depends upon the concentration of the original waste, almost without exception increasing as the concentration increases. The cost of another set is independent of the concentration.

The costs of most of these processes under a set of median conditions of the major parameters are shown in Figure 2-1. The costs for this set of conditions run from \$.038/Mg for injecting at the plant site to \$1.92/Mg for pipelining to the sea.

Conveyance of the waste relatively short distances prior to injection markedly increases the cost of the over-all process.

It is possible to reduce the cost of pipelining to the sea in two ways. One, by seeking a closer land dump here taken at 50 miles. Two, by evaporating the waste prior to pipelining. That the curves for both of these processes seem to converge at low concentrations in the region of \$.30-.40/Mg is a happenstance of the choice of the data. The cost of the evaporation at low concentrations is about \$.28/Mg and this makes up the largest part of the cost of the processes involving it. Processes involving a land dump at 50 miles conveyance have the conveyance costs as the major component. This at 50 miles is about 1/6 of the pipelining cost at 300 miles, again approximately \$.32/Mg. It also happens that at these concentrations and distances the cost of freighting the dry solids is almost the same as the cost of pipelining the saturated liquor. Thus several types of processes converge on the \$.30-.40 region.

It should be emphasized that Figure 2-1 represents only one set of conditions chosen to be median of the ranges of parameters normally expected. However, changes in the parameters may be quite marked and some of them may have a considerable influence on the relative costs of the various processes. All the information necessary to calculate a similar economic choice chart for any other values of the parameters are contained in the body of the report. Judgements about relative position of the processes for other values of the parameters should be made from Figure 2-1 only with the greatest discretion.

Among such judgements that may be pointed out here are the following:

> The cost of evaporation in soil-cement lined tanks is ~~as~~ stated about \$.28/Mg at low concentrations. Evaporation in unlined tanks is very much cheaper, approximately \$.04/Mg. Thus if it should prove

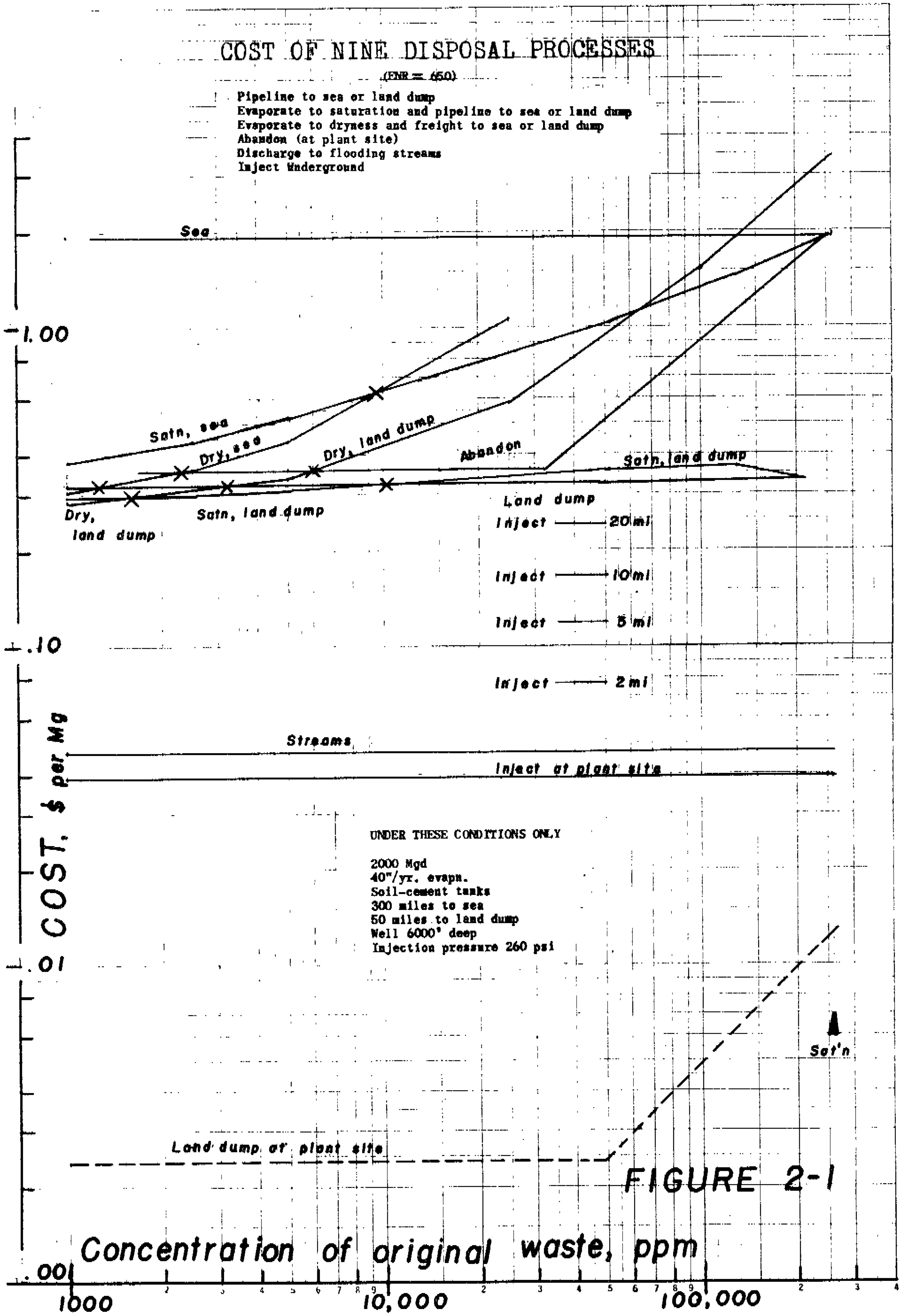
COST OF NINE DISPOSAL PROCESSES
(ENR = 650)
Pipeline to sea or land dump
Evaporate to saturation and pipeline to sea or land dump
Evaporate to dryness and freight to sea or land dump
Abandon (at plant site)
Discharge to flooding streams
Inject Underground
Sea
1.00
.10
.01
.001
COST, $ per Mg
Satn, sea
Dry, sea
Dry, land dump
Abandon
Satn, land dump
Land dump
Dry, land dump
Satn, land dump
Inject 20 mi
Inject 10 mi
Inject 5 mi
Inject 2 mi
Streams
Inject at plant site
UNDER THESE CONDITIONS ONLY
2000 Mgd
40"/yr. evapn.
Soil-cement tanks
300 miles to sea
50 miles to land dump
Well 6000' deep
Injection pressure 260 psi
Sat'n
Land dump at plant site
Concentration of original waste, ppm
1000
10,000
100,000

FIGURE 2-1

possible to use unlined tanks the processes involving evaporation would converge at low concentrations toward something like $.06-.08/Mg. In other words, they would be much more competitive with injection than is now the case.

The conveyance costs have been calculated for pipelining. It is possible that canaling where applicable would prove cheaper than pipelining. If canaling did significantly decrease conveyance costs it would affect the cost of the processes involving direct conveyance but not of those involving evaporation prior to conveyance for in these the conveyance is only a small portion of the total. Canaling would have to reduce the conveyance cost to 1/50th in order to be competitive with injection.

As a third illustration, if one were fortunate enough to have land suitable for land dumping and abandoning immediately adjacent to the plant site, then disposal figures shown as the dashed line in Figure 2-1 would be extremely low. However, the cost of conveying even a very short distance would soon overbalance this advantage. For example, pipeline conveyance only two miles would bring the cost up to slightly more than injection at the plant site.

Relation to Water Costs

The costs here developed, per Mg of waste, have a complex bearing on the cost of water conversion. The cost of the disposal process must of course be expressed as $/Mg of product water and added to the conversion costs. For a given concentration of waste this places the advantage with those conversion processes having high product-to-waste ratios. The product-to-waste ratios of many currently favored conversion processes is 1:1 and for these the figures of the present report in $/Mg of waste may be added as is to the conversion cost. The electrolytic membrane process has a product-to-waste ratio of as high as 4 or 5:1. Thus if all processes produced waste of the same concentration the electrolytic membrane process would have about one-fourth the waste disposal cost per Mg of product. This advantage is tempered somewhat when comparison is made on the basis of equal concentrations in the feed, for in that case the high product-to-waste ratio process would produce a more concentrated waste which in some disposal processes is more costly to dispose of. A more important reservation is that the product-to-waste ratios characteristic of the various conversion processes result from a limit on the concentration of the waste rather than its volume ratio to the product. This subject is not gone into in the present investigation which is confined to waste disposal costs. It is cited as an example of one of the purposes of the study, namely to stimulate in the engineering of conversion processes a consideration of how waste disposal costs may alter the optimum process characteristics.

OPERATIONS

Pipeline Conveyance The investment costs for liquid pipelines developed in this study correlate well with those for actual and estimated water pipelines and also with those for petroleum pipelines. The conveyance costs for pipelining developed in this report correlate well with estimated and actual costs of water pipelining over a wide range of capability by the empirical equation

$$\text{Cost in \$/Mg.} \simeq .2006/Q^{0.45218}$$

where

Q is the capability, Mgd.

Oil pipeline conveyance costs are about twice the water figures at corresponding capabilities

Solar Evaporation It is widely reported that salt water cannot be held in unlined earthen tanks even when they have "impermeable" clay bottoms because the salt water flocculates the clays and makes the structure porous. This is important and unfortunate because lining the earthen tanks with soil-cement or concrete increases the cost by about 30-fold and 70-fold respectively.

Investment costs \$/Mgd and operating costs \$/Mg are developed for various brine evaporation rates.

Brine evaporation rates in the United States are studied and it is shown that the area having economic evaporation rates is quite restricted to the southwestern states. The area having net brine evaporation above 30 inches annually is confined to West Texas, most of New Mexico southern and western Arizona, southern California and the southern California-southern Nevada desert where the evaporation reaches its United States maximum of about 60 inches. Solar evaporation of brine in the sense of the report is not economically possible east of central Texas and central Kansas and north of California, Nevada, Utah, Colorado.

A correlation is shown between net water evaporation rates and net brine evaporation rates apparently independent of gross evaporation and precipitation.

Injection There is a large body of current practice on injection of oil well brines but only a few industrial wastes are currently injected underground. Generalized figures are developed for the costs of injection wells depending on depth and capability. Figures are likewise developed for the costs of injection depending on depth, capability, and casing head pressure encountered. The capacity of storage underground is shown to be tremendous, periods of centuries or millenia being required for the liquid to travel even a few miles.

Land Dumping
Abandoning
Discharge to
the sea

Large areas of low cost land exists in the western and southwestern states which might be used for land dumping or abandonment of wastes. Calculated on the basis of building up no more than 10 feet of dry salts in a century (in case there should be no seepage), this is an exceedingly cheap operation. Discharge to the sea also involves no cost. It is shown that Great Salt Lake constitutes a "sea" for the purposes of this study since its present evaporating capacity which appears to exceed the inflow is sufficient to absorb the saline water conversion waste from plants capable of supplying 15 million urban population.

Discharge
to Streams

The controlled discharge of waste into the flood waters of the sporadic arid-region streams is one of the cheapest disposal methods. It is shown for example that the Canadian River near Amarillo has a flow less than the average daily flow for 90% of the time. The remaining 10% of the days have flood flows at total dissolved solids concentrations significantly less than those encountered during the remaining 90% of the days. In each of two recent drought years the river could have carried 50,000 tons of additional salts in these flood flows without ever exceeding the average concentration of the low flows. This would accomodate the wastes from a 2000 Mgd conversion plant operating on a 15,000 ppm feed.

PROCESSES

Convey to
the Sea

In the western states a certain portion of the lands is more than 500 miles from the sea or Great Salt Lake. Of the remainder only 15% is within 100 miles of these and 50% is between 100 and 300 miles. Thus only a small proportion of the land could enjoy conveyance distances of less than 100 miles for discharging to the sea. Pipeline conveyance to the sea is economically prohibitive except at very large capabilities and quite short distances from the sea.

At greater distances from the sea the cost of disposal by pipeline conveyance may be reduced by evaporation to saturation prior to conveyance. This reduces the cost depending on concentration. But the reduction becomes less and less at shorter distances until at some critical distance it becomes more expensive to evaporate than to pipeline the original waste. This critical distance varies with all parameters but is not very sensitive to concentration. At 40 inches evaporation it is about 50 miles for the 2000 Mgd case and about 7 for the 20 Mgd.

A rather striking conclusion is that there is considerable region for economic choice between evaporating to saturation and pipelining, and evaporation to dryness and freighting the resulting solids by railroad. In areas where there are no possibilities for injection or discharge to flooding streams (which under selected conditions are much cheaper than either of the above) a competitive situation between railroading and pipelining may be looked for. The economic choice depends on distance and concentration. Railroading is cheaper up to concentrations of about 18,000 ppm at 500 miles and 9500 ppm at 300 miles. Pipelining is cheaper above these concentrations. The critical concentrations are not greatly affected by changes in cost of evaporation.

Convey to a Land Dump The cost of the land dumping operation is so small that the costs of the processes involving it are practically identical with the costs of the intermediate operations in those processes such as conveying or evaporating. As has been shown evaporation to saturation is of no advantage over direct pipelining when the distances are only 50 miles although this distance is reduced to about 7 miles at low capabilities. At the 2000 Mgd capability, there is a small region of concentration up to 3500 ppm where evaporation to dryness and railroading is cheaper than pipelining 50 miles. Land dumping remains however primarily a device to lower disposal costs by seeking shorter conveying distances for dumping than those to the sea. It is assumed that inland areas might locate land dumps which are nearby compared to the sea but remote with respect to nuisance and pollution from them.

Abandonment Abandonment at the plant site is sought as the ultimate reduction of conveying distance. If this is to be done generally, (and not just for certain specific fortunate locations) it requires not only abandoning large acreages forever but also constructing and maintaining forever tight structures to hold the salts. These structures turn out to be the major cost and place abandonment among the high cost processes. Furthermore none of the major parameters except evaporation rates have any affect in lowering the cost.

Injection Injection has the lowest cost of all the processes likely to be useable generally. Its major drawbacks are that sites suitable for injection wells are not found everywhere and their locating involves a certain unpredictability. The same unpredictability holds for the associated pumping costs. The injection process is well worked out through oil field practice and the capacity of underground formations to absorb liquids is tremendous. Whether this will hold for injection to a non-producing formation remains to be seen. Nothing is gained by seeking an abandoned well, for the saving in well costs after reconverting it are less than the conveyance costs which would be incurred if the well happened to be located (as is likely) more than a mile or so from the plant. Indeed if for any other reason it is necessary to convey the waste even to a new well the conveyance costs very quickly wipe out the favorable cost of injection. The cost of injection cannot be lowered by prior evaporation because the cost of evaporation is more than the difference in injection costs.

Flooding Streams The total potential of the country for discharging to flooding streams may not be very great even though the process may be one of the cheaper processes for individual plants. Especially of importance is the effect of such discharge on flood water storage downstream. There are many legal problems which have not been explored in this study.

By-products from Wastes

By-product manufacture from the wastes will probably have few potentialities except when solar evaporation is a component of the waste disposal process. In that case a desirable raw material for the manufacture of certain of the minor components such as iodine, bromine, magnesium, might result. Manufacture of either minor or major (heavy chemical) by-products would be limited because the waste production of only a few reasonable-size water conversion plants would swamp the U. S. market for the materials. Thus although by-product manufacture might be profitable for a few organizations it cannot be of general assistance to the waste disposal problem when saline water conversion plants become numerous.

Recommendations

The uncompleted aspects of the work and recommendations for further study are contained in the next chapter.

CHAPTER 3

RECOMMENDATIONS

The recommendations for further research arising out of this study fall into five categories as follows:

I. An extension of the comparative curves such as Figure 2-1 to cover all values of the major parameters.

II. A study of the possibilities for major reductions in costs of certain operations.

III. A study of the cost of conveying water.

IV. A more detailed study of the geographical incidence of the values of the major parameters to define the areas in which the various processes are applicable.

V. Refinements, improvements, and settling of questionable points in the present study.

* * * * * * * * * *

I

EXTENSION TO ALL CONDITIONS

Figure 2-1 indicates with deceptive conciseness that discharge to flooding streams and injection are preferred methods of disposal on the basis of cost, and that all other processes are at least eight times as expensive. The deception arises through the fact that Figure 2-1 applies only for the specific set of conditions there cited. While those conditions are chosen to represent the average of the reasonable ranges of the major parameters, this average of course cannot express the conditions as they exist generally. An attempt has been made in the chapters on the individual processes and individual operations to make some assessment of outstanding effects of parameters but it is not possible to assess the effects of the parameters on the relative standing of the various processes without actually making the calculations. As a very simple illustration it should definitely be determined whether the relative standings as shown in Figure 2-1 are appreciably altered at lower capabilities -- for it is likely that these low capability plants will be the pioneer plants in saline water conversion. The first recommendation therefore is that the methods and data developed in this report will be utilized to extend the study so as to cover, in the manner of Figure 2-1, the full range of the major parameters which are:

Capability
Evaporation rate
Evaporation tank construction
Distance to the sea
Distance to a land dump
Depth of well
Injection pressure

Such studies which can now be largely routinized may allow some definite conclusions to be drawn where now only suggestions can be made.

II

MAJOR COST REDUCTION

Of the eight major parameters five are geographical or geological in nature and completely outside of engineering control. Only two, capability and type of tank construction, are completely within engineering control. One, concentration of original waste, is somewhat subject to engineering control. The second recommendation deals with the measures that might be taken to make substantially more favorable those parameters subject to engineering control.

Under conveyance, it is recommended to determine the generalized possibilities for utilizing canal sections to a major extent in the conveyance system. This will involve generalized studies of land slope to determine areas in which canals are feasible. It will also involve a determination of the unit investment cost and operating costs for canals similar to the present work on pipelines. It is generally believed that canaling is cheaper than pipelining but the author has found that objective evidence for this is quite elusive. Obviously a canal has a chance to be cheaper than a pipeline when the canal operates under gravity and the pipeline has to overcome a pressure head. This is particularly true if it should be found that investment costs per unit of capability are lower than pipeline investment costs. But this applies only to a canal and a pipeline side by side. The question becomes more complicated when a generalized terrain is assumed and it becomes necessary to determine whether in general a pipeline might take a direct route whereas a canal in following the contour might lose its per-Mg advantage.

There is some evidence that under generalized conditions investment costs, at least for canals, are less than for pipelines for equal capability. For example, the cost of 54 miles of cut-and-cover conduit of capability 1,038,000 Mgd in the Colorado Aqueduct of the Municipal Water District of Southern California was $.0011 (ENR = 650) while the cost of 62 miles of lined canals of the same capability was $.00054. Incidentally, the figure for cut-and-cover conduit fits very well on the extension of Figure 4-4. The capability is 10 times greater than the highest capability shown on that Figure.

But there is contrary evidence. For example, the estimated operating cost of the Bureau of Reclamation's Gulf Coast Canal correlates very well with the curve of Figure 4-5 at a capability of 11,800,000 Mgd. Since that curve is composed entirely of pipeline figures one would expect that the canaling figure would show too low a cost to correlate with the extension of the curve. This brings up a question of whether the alleged low unit cost of canals is not ascribable to the generally high capability of these structures rather than to any inherently lower cost over pipelines of the same capability.

The second parameter in which engineering control can have a major effect is the type of evaporation tank structure. If the work outlined under Recommendation I indicates that evaporation costs in the region of those for unlined evaporation tanks do have appreciable effect in lowering the cost of some processes or particularly of altering their cost relationships then a rather thorough study should be made of solar evaporation with a view to lowering its cost substantially. Such cost lowering can only come through the cheapening of the tank accomplished by using essentially unlined tanks. Figure 5-2 shows that evaporation in unlined tanks costs about one-eighth that of evaporation in soil-cement tanks. The major technical question is whether unlined tanks can be made to have a seepage low enough to prevent pollution. As indicated in the report the evidence from this seems unfavorable but questionable. Furthermore, there may be some simple method, say akin to bentonite lining of fresh water reservoirs, which may reduce the seepage sufficiently. The self healing tanks used in South America are suggestions of what might be accomplished.

Reduction of evaporation costs to a lesser extent are suggested in the use of dye and the maintenance of stratification in the evaporating tank. Experimental studies should be carried out on both of these if the results of Recommendation I show that a 30% saving in evaporation cost might be significant. In arriving at this figure it is assumed that the dye method will not increase the rate more than 20% and the stratification method not more than an additional 30% for a total of 50% increase. Among things to be studied would be the allegation that the dye used in the Israel work is not lightfast and soon fades out.

III

COST OF CONVEYING WATER

This study has again shown the necessity, for water resource planning, of comprehensive studies leading to rule of thumb figures on the costs of conveying water. The chapter on conveyance in this report demonstrates that despite wide variations in terrain, capability, and other conditions, it is possible to achieve some reasonable correlation of conveyance costs. Indeed, when the figures for the Colorado Aqueduct and the Gulf Coast Canal are placed on a chart similar to Figure 4-5, we achieve a correlation, not perfect but good enough to be illuminating and useful, over the 600,000-fold range in capability from 20 Mgd to 11,800,000 Mgd and a 650-fold range in unit cost with an average deviation of all points from the correlation curve of less than 15%.*

*FOOTNOTE: The equation of this line is $C_{CQ} = 0.2706/Q^{0.48347}$

IV

GEOGRAPHIC AREAS OF APPLICATION

Another type of recommendation involves further investigation of the parameters not under engineering control which are evaporation rate, distance to the sea, distance to a land dump, depth of injection wells, injection pressure, While nothing can be done about these parameters in the sense of altering them yet their geographical distribution should be studied in order to arrive at a firmer definition of the areas in which the various processes are applicable.

In injection a study should be made to see if the range of casing head pressures used in the report which were selected from Texas conditions is truly applicable throughout the United States or whether the report conditions are significantly more or less favorable than would be experienced nationwide.

In land dumping a geographical and geological reconnaissance study should be made to determine the existence and distribution of suitable land dumps in the western states. The report assumed that where these exist a 50 mile distance will be reasonable. If further geographical study indicates that this 50 miles should be increased to 100 or decreased to 20 it would have a significant effect on the land dumping process. The same study could locate sites suitable for abandonment and in this phase it would be desirable at the same time to obtain actual prices for land, which in the report are assumed to be significant for abandonment though not for land dumping.

In sea discharge investigation from an oceanographic standpoint should be made on the effect of discharging such quantities of these wastes into the sea near the shore. Included should be a study on the effect of marine and beach life, including human, and of the inshore currents which will distribute the waste. A reconnaissance study of this type should locate those areas along the indicated coasts where it would not be desirable to discharge these quantities of waste. This might exclude enough length of the seacoast to appreciably change the pattern of distance to the sea as shown on the map. Also it might indicate areas where even littoral plants could not discharge wastes without contaminating their own intakes.

Also, a more detailed study should be made to determine the suitability of Great Salt Lake as an ultimate disposal sump for saline water conversion wastes. The effects on the water body on the surrounding population and on the plans of chemical companies for utilization of its brines should be studied in greater detail than has been possible in this report.

In discharge to flooding streams a study should be made to determine the general applicability of the process. The question to be answered is: Where else in potential brackish water conversion areas besides the Canadian River at Amarillo can the streams take any appreciable quantity of wastes in flood flow. The answer to this will tell how many plants the country's streams can tolerate and roughly where.

Related to this category is a more comprehensive study of the possibility of producing by-products from waste especially evaporated wastes. This study would consider the types of minerals normally found in brackish water or sea water and, selecting those which might be favorably produced from the waste, would determine in what locations they might be produced, how much of the market they might capture and how much of a profit might be realized on the operation which might be credited back against waste disposal. (It is rather doubtful that such profits would be credited in this precise way but the over-all effect would be a greater profit for the integrated water conversion-by-product plant.)

V

REFINEMENTS

The final group of recommendations comprises the category of refinements, improvements, and settling of questionable points in the method and data of the report.

In conveying more precise study should be made of the cost of pipelining utilizing generalized conditions of pipeline profile i. e. containing high and low spots and determining the economic optimum pipe size for lowest operating costs using the parameters developed for the pipeline itself. This will automatically involve consideration of the question as to whether the pipeline can be run economically as a siphon without using any power.

The report sidesteps the question of materials of construction for the pipeline as well as for the injection wells and other structures. Further inquiry should determine the materials which are best suited and most economical to handle the brine as well as the costs of utilizing the indicated materials.

Some minor investigation might be given to the fact that oil conveyance costs are higher than water conveying costs whereas the investment costs are about the same.

More attention should be given to conveying for short distances. Accurate short distance conveyance data are especially desirable in connection with the effect of conveyance on injection short distances from the plant site.

Under evaporation certainly more attention should be given to the operating experience built up by the operators of solar evaporation vats in this country and abroad.

This study has assumed that no treatment of brines prior to injection will be needed. This should be explored further for cases of chemical incompatibility will probably arise. Especially it is likely that solar evaporation might so alter the brine in turbidity and supersaturation as to require treatment before pipelining. If evaporation can be made cheap enough so that injection of evaporated brine becomes economic then treatment prior to injection should be studied.

A study should be made of the types of solids which will be obtained from evaporation to dryness of saline water conversion wastes for the purpose of determining how they may be loaded and what type of freight car and what type of commodity rate would apply to them.

Uncertainty exists as to the accuracy of the Harbeck ratios due to an insufficiency of standard data on natural brine evaporation rates. Brine evaporation experiments should be carried on presumably at standard Weather Bureau stations in such a way as to obtain design data that will fit in with the current scheme of data for water evaporation. At the same time or independently of this the Harbeck ratios should be calculated for other conditions of humidity, temperature and pressure than those used in this report. Some attempt should be made to put the Israel brine pan experiments into standardized form which would integrate with the American data.

The 21 station network used in calculations for this report is quite scanty and should be extended to include other stations so as to better define the lines of equal evaporation. At the same time the evaporation correlation curve, Figure 5-5, should be checked for applicability over this wider range of data.

The data on permeability of concrete is shown in the report to be rather scanty and open to some question. The same is almost certainly true in much greater measure for soil-cement. The available data should be collected and new determinations made if pollution-free evaporation is to be carried out.

Finally, the effect of non-uniform annual evaporation should be studied for its effect on the evaporation operation. This is one of a type of parameters, which include stream flow applicable to discharging to streams, which vary in such a way that the annual average cannot be used in detailed engineering studies. It is necessary to make a statistical study of the distribution of daily evaporation or stream flow and compute the necessary evaporation tank volumes or storage volumes by accumulating the day-to-day inflow and outflow, using statistical methods to take a calculated risk.

For injection a careful study should be made of the mechanics and mathematics of injecting into a non-producing formation. This may have a considerable bearing on the injection process and therefore it should be worked out with some care and detail.

On discharge to streams a study should be made of the effect on downstream reservoirs and consumers and a re-evaluation of concentration limits might result from such a study. Also in the report it is indicated that there is some discrepancy between the salt tonnage carried as calculated by the day-to-day or hour-by-hour integration of the published references as compared with the longer periods used in the report. This discrepancy should be investigated to see what is the maximum size of period that can be used for computation without seriously affecting the accuracy of the results. Some attention should be given to the need for and cost of supervision, river monitoring and maintenance in a controlled discharge program.

CHAPTER 4

OPERATION: CONVEYANCE

Synopsis - COST OF FREIGHTING SOLIDS: Freight Costs, Cost of Freighting Solids - COST OF PIPELINING LIQUIDS: Unit Cost of Pipelines, Cost of Pumping Facilities, Pipeline Investment Costs Calculated, Pipeline Conveyance Costs Calculated, Conveyance Costs Experienced, Lowering Pipeline Costs - REFERENCES

Synopsis This chapter develops the types of structures and costs applying to the conveyance of liquids and of solids over distances up to 1,000 miles.

The railroad is generally conceded as the economic method for long distance hauling of bulk solids and thus the cost of solids conveying becomes simply the conversion of the corresponding freight rates, plus the cost of loading.

Conveyance of liquids over long distances however is more complicated. The major form of long distance conveyance now in practice are the pipelines for conveying petroleum products, as well as water. Also in use are open canals. Open canals are probably a cheaper means of conveying water and brines. Two factors excluded them from this preliminary consideration. The first factor is that open canals can only transport approximately on the contour. Accordingly it would be more difficult to generalize on costs as must be done for this study. Secondly, cost data on canals for long distance conveyance are quite scanty in the technical literature.

A pipeline however can be specified for any sort of terrain condition. Also, there are more available cost data on pipelines. The situation however is far from favorable for economic studies in water resources.

The present chapter will illustrate the fact that there is badly needed a study of "the cost of conveying water" and the presentation of the results in a readily useable form that will allow rule-of-thumb computations to be quickly made. Such a guide is absolutely necessary if we are to make the higher order economic studies which are necessary to the nationwide development of water resources.

The present chapter barely skims the surface of the subject in order to provide some preliminary data for the ultimate objective of the present study. Even so it has been necessary to go to quite extreme lengths, in order to arrive at a result. In the present chapter, the engineering detail to which it is necessary to resort in developing economic data on water conveyance is aptly compared with the extreme simplicity of developing comparable data on freighting solids.

The situation that confronts the student of water economics may be compared with the accomplishment to be expected from market research if each market researcher instead of referring to freight schedules had to calculate them, starting with the cost of constructing a locomotive and laying track -- or similarly, if the student of international trade had to begin each problem with an engineering estimate of the construction and operating cost of steamboats.

Conveyance Unit Freight costs depend upon the mileage, the competitive situation, the value of the commodity, and its difficulty in handling. There is no commodity rate for the salts that would be obtained by evaporation of saline water conversion wastes. However, in Figure 4-1 there is shown the unit rate for common salt bulk, and rock salt from Weeks Island, Louisiana, a producing point. These are the actual carload rates including tax in effect in February 1957 (4-1). On the basis of their value saline water conversion salts might be aligned with rock salt, but on the other hand they would be more difficult to handle and probably more corrosive than rock salt. Accordingly, our calculations are based on the common salt rate shown in the Figure. A study has not been made of the variability of the freight rates from various producing points throughout the Southwest. It has been assumed that these rates are characteristic of conditions in the area most likely to utilize conveyance of saline water conversion wastes.

Cost of Freighting Solids The cost of freighting solids resulting from evaporation to dryness of wastes is compounded of the freight costs and the cost of loading. It is assumed that the loading is done with earth moving equipment and will approximate the cost of that operation, as developed in Chapter 5, say \$0.27/cu yard. At an estimated bulk density of 100 pounds per cubic foot of salts this amounts to \$0.20/ton. The cost of conveying solids per Mg of original waste, including loading and freighting is thus:

$$C_{Cs} = 4.1725 \times \frac{C}{10^6} (f \times d + 0.20), \$/Mg$$

where

C = concentration of waste, ppm
f = freighting cost, \$/ton mile
d = distance, miles.

Selected values are shown in the following Table.

TABLE 4-1

COST OF CONVEYING SOLIDS, \$/Mg ORIGINAL WASTE

Concentration ppm	50 mi.	100 mi.	300 mi.	500 mi.
1000	.0123	.0188	.0334	.0425
2500	.0307	.0467	.0835	.1060
5000	.0615	.0935	.167	.212
25,000	.3075	.467	.835	1.060
100,000	1.23	1.88	3.34	4.25
260,000	3.18	4.85	8.66	11.00

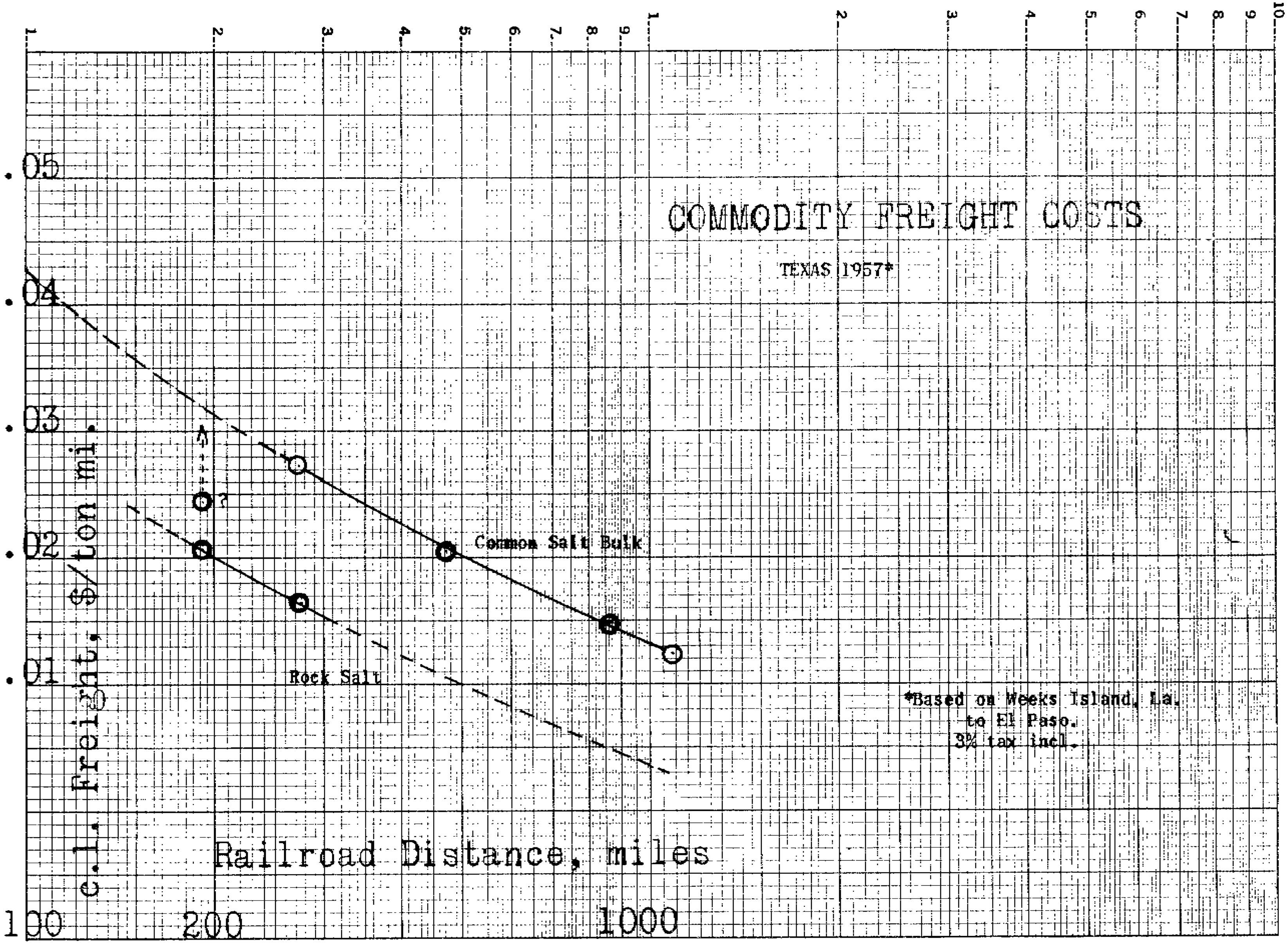
COMMODITY FREIGHT COSTS
TEXAS 1957*
Common Salt Bulk
Rock Salt
*Based on Weeks Island, La. to El Paso. 3% tax incl.
c.l. Freight, $/ton mi.
Railroad Distance, miles
.05
.04
.03
.02
.01
100
200
1000

FIGURE 4-1

COST OF PIPELINING LIQUIDS

Unit Cost of Pipelines

Petroleum pipelines and water pipelines have enough similarities so that their construction and operation may be considered as part of the same art. Petroleum pipelines are usually constructed of steel while water is conveyed either in steel or in reinforced concrete, and sometimes even in wood. Petroleum pipelines tend to be of smaller diameter and smaller capability than water pipelines but on the other hand averaging much longer than these. Petroleum pipelines less than 100 miles long are rather scarce while water pipelines greater than 100 miles long are equally so. Petroleum is usually pumped under pressure the entire distance of the line. Also, partly because petroleum pipelines may carry a number of products simultaneously and are more likely to experience trouble, they tend more to control, maintenance and communication systems. Water pipelines usually do not require so much attention.

More cost data is available on petroleum pipelines than on water. Enough of both for our present purposes is shown in Figure 4-2. The data for water pipelines all refer to specific pipelines. Those for oil refer to averages of experience figures for existing pipelines as well as the results of some standardized estimating procedures for pipelines. Some of each type include the pumping stations, while some do not. As later shown, pumping station costs amount to only about 10% of the average pipeline cost.

All the costs shown, as throughout this work, have been calculated to an ENR cost index of 650. Pumping station costs have been withdrawn from the original costs where that is possible.

The unit cost of a one inch pipeline has been calculated by taking the nonpipe costs of pipelines (4-2) (right of way, surveying, clearing, laying, ditching by machine and inspecting) which total $1800 per mile and adding the price of the pipe at 32 cents per foot per inch of diameter (see Chapter 6) and of hauling and stringing at 30 cents/ton mile (4-2).

Cost of pumping facilities

In considering the unit cost of pumping facilities a distinction must be made between process pumps installed in a plant and pump stations on a pipeline. As shown by Figure 4-3 the latter cost about four times as much as the former in the capabilities where they overlap. Pump stations on a pipeline require land, buildings, utilities, controls and sometimes housing which are not needed for process pumps in an operating plant.

The Figure indicates, as found with pipeline costs, that water pumping facilities cost about the same as oil pump stations of the same horsepower. Undoubtedly a great deal more data of this type could be collected but the scope of the present study did not allow it especially since the cost of pumping facilities is small compared to the total costs.

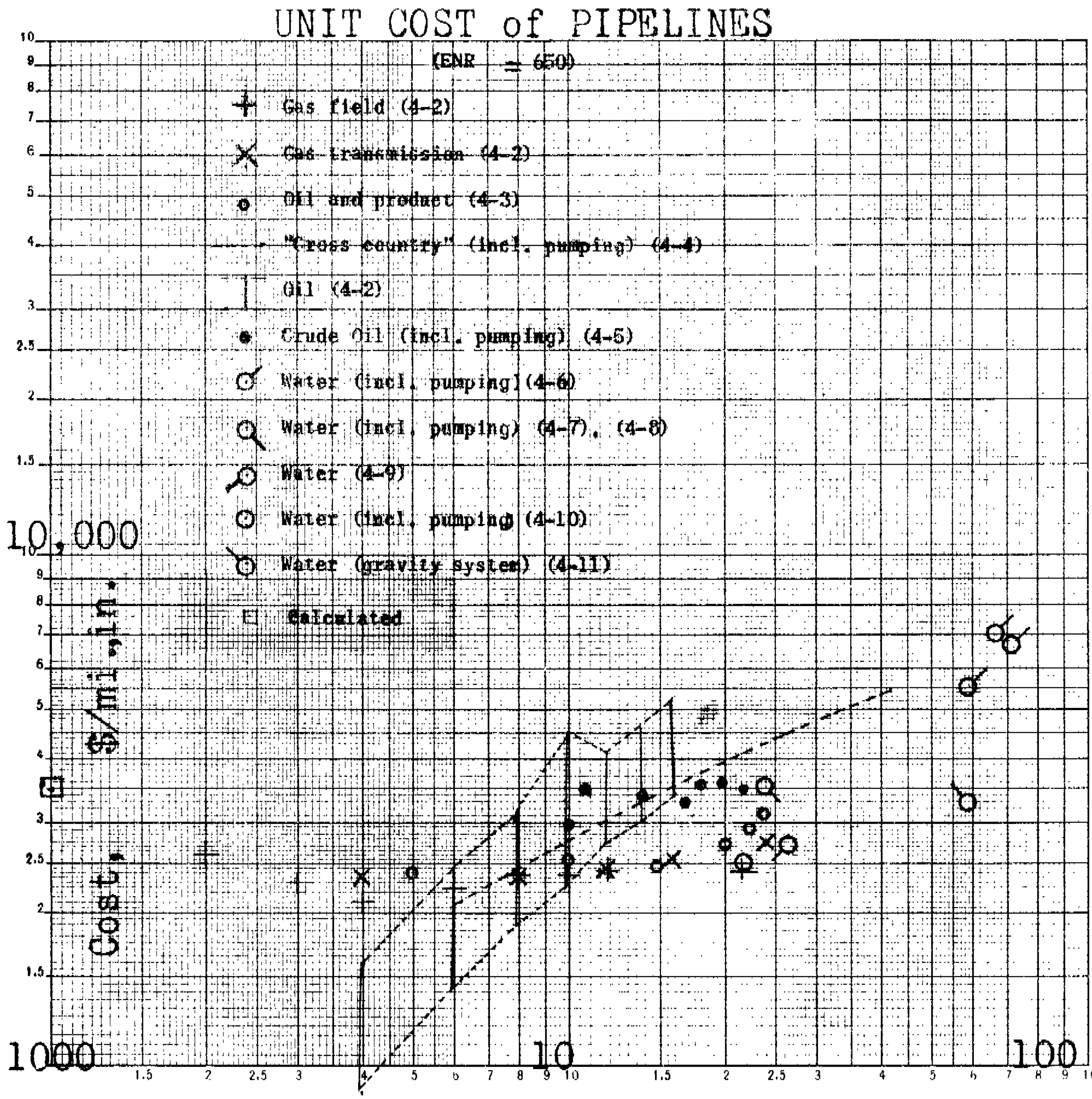
UNIT COST of PIPELINES
(ENR = 650)
Gas field (4-2)
Gas transmission (4-2)
Oil and product (4-3)
"Cross country" (incl. pumping) (4-4)
Oil (4-2)
Crude Oil (incl. pumping) (4-5)
Water (incl. pumping) (4-6)
Water (incl. pumping) (4-7), (4-8)
Water (4-9)
Water (incl. pumping) (4-10)
Water (gravity system) (4-11)
Calculated
10,000
1000
10
100
Cost, $/mi,in.
Diam. of line ID, in.

FIGURE 4-2

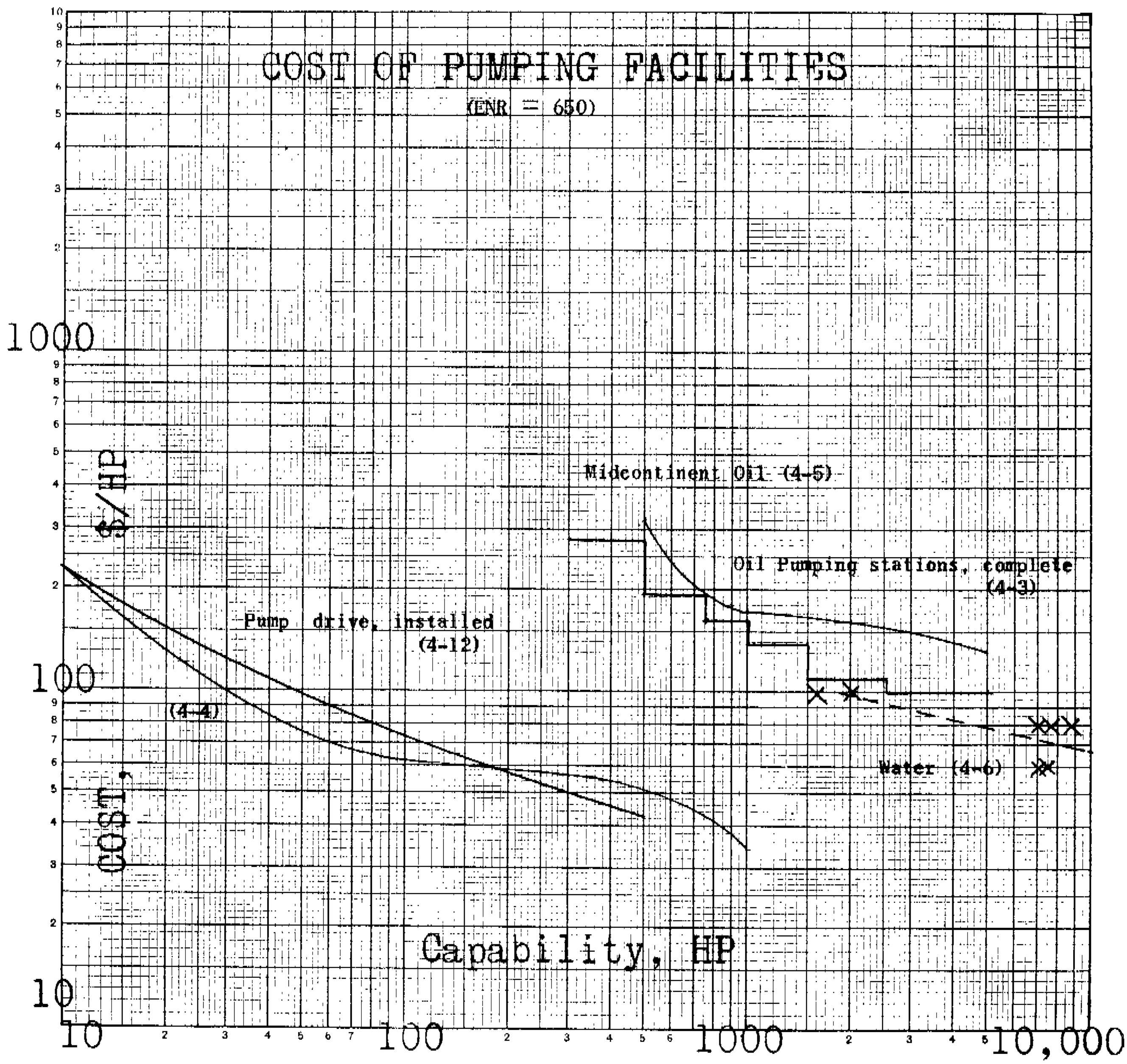
COST OF PUMPING FACILITIES
(ENR = 650)
Midcontinent Oil (4-5)
Oil Pumping stations, complete (4-3)
Pump drive, installed (4-12)
(4-4)
Water (4-6)
COST, $/HP
Capability, HP
1000
100
10
10
100
1000
10,000

FIGURE 4-3

Pipeline Investment Costs, Calculated

Using the above figures, we are now in position to make a rule-of-thumb calculation of the investment cost of pipelines for our chosen capabilities of 20, 200, 1,000, and 2,000 Mgd. Numerous studies could be made to select the optimum combination of pumping facilities and pipeline size. For our purposes, this will be shortcut using an economic pipe diameter nomograph (4-13). It is to be noted that this particular chart refers to process piping and may not be necessarily correct for long pipelines. The results of this approach are as follows:

Mgd	20	200	1,000	2,000
Economic ID in.	1.5	4.0	7	10
Pipe Size Chosen	2"	4"	7 5/8"	10"
Actual ID in.	2.06	4.03	7.03	10.02

The actual inside diameters do not correspond to any one schedule (i.e. strength) of pipe but are shown only to indicate that such diameters are available in the sizes chosen. An actual engineering calculation would establish the exact size, weight and thus cost of pipe by more precise methods. The 7 inch ID pipe is not standard steel pipe but corresponds to 7 5/8" oil well casing.

Having established a pipe size, the friction pressure drop may be obtained from a standard nomograph (4-14) for the Hazen and Williams formula, C=100. The pumping head will be made up of the friction loss and the differences in elevation between the various points on the line. It would not be possible in this study to cover the various combinations of elevation differences which might be involved and accordingly the head loss is calculated purely as the friction loss in the pipe. This has some justification in that one of the main purposes of pipeline would be to convey wastes to the sea coast, almost universally a negative difference of elevation. However, of course, the total ΔH will be in many cases greater than the difference in elevation due to the crossing of intermediate divides and the nonrecoverability of the potential energy thus generated. Users of the charts herein should be cautioned that just the reverse will apply when water (e.g. sea water for conversion) is pumped from the sea coast to inland points. In those cases a gradient of at least 4-5 feet per mile (e.g. typical of the Gulf Coastal Plain) will be encountered. As may be seen this increased head of about 1 foot per thousand feet would not have a great effect on the horsepower, however. The results are:

Mgd	20	200	1,000	2,000
ΔH ft./1,000	15	25	26	27
Ft./sec.	1.7	3.7	5.5	5.5
HP/mile	3.5	5.8	30.2	16.2

The horsepower has been calculated at 80% pump efficiency by:

$$\text{HP/mile} = 0.00116 \times \Delta H \times \text{Mgd}$$

Costs of the pipeline per mile may now be read from Figure 4-2 and of pump stations from Figure 4-3 assuming that the horsepower size at each station is such as to give one station every 50 miles on the line. These results are as follows:

Mgd	20	200	1,000	2,000
Line Cost $/mi. in	2600	2200	2400	2800
Line cost $/mi.	5200	8800	18,300	28,000
Pump station cost $/HP	160	200	100	160
Pump station cost $/mile	55	1160	3020	2600
Total investment $/mile	5250	9960	21,320	30,600
Pump station as % of total	1%	11.6%	14.2%	8.5%
Total investment $/mile gpd	0.263	0.0500	0.0213	0.0153

Pipeline Investment Costs, Experienced

Some data are available on the investment costs per unit of capability for liquid pipelines. These are shown in Figure 4-4. The costs of water lines correlate well with those calculated in the previous section for smaller capabilities, and also with the one set of data available on oil pipelines.

Again there are probably available numerous other data which might be recalculated and correlated. It is believed however, that the Figure 4-4 indicates that our calculated investments costs for liquid pipelines are reasonably accurate. It also constitutes evidence, believed to be the first, that water pipeline costs and oil pipeline costs are the same for equal capabilities. This means that the data on oil pipelines which though scarce are much more extensive than those on water pipelines.are available for use in studying the economics of water resources. The above figures glide over such detailed differences as materials of construction for pipeline (steel, concrete, asbestos-cement, concrete lined, plastic lined, etc.) type of terrain (hilly, rocky, downhill, uphill), cost per acre for easements. It is not possible to consider all these details in a first broad view but refinements of this study should incorporate them. In particular as discussed in Chapter 6, Operation: Injection, attention should be given to the ability of the materials to withstand inside corrosion from the salt water. For the present it is assumed that concrete pipe would be used rather than cement-lining steel pipe if that is necessary.

LIQUID PIPELINES
Investment Costs
(ENR = 650)

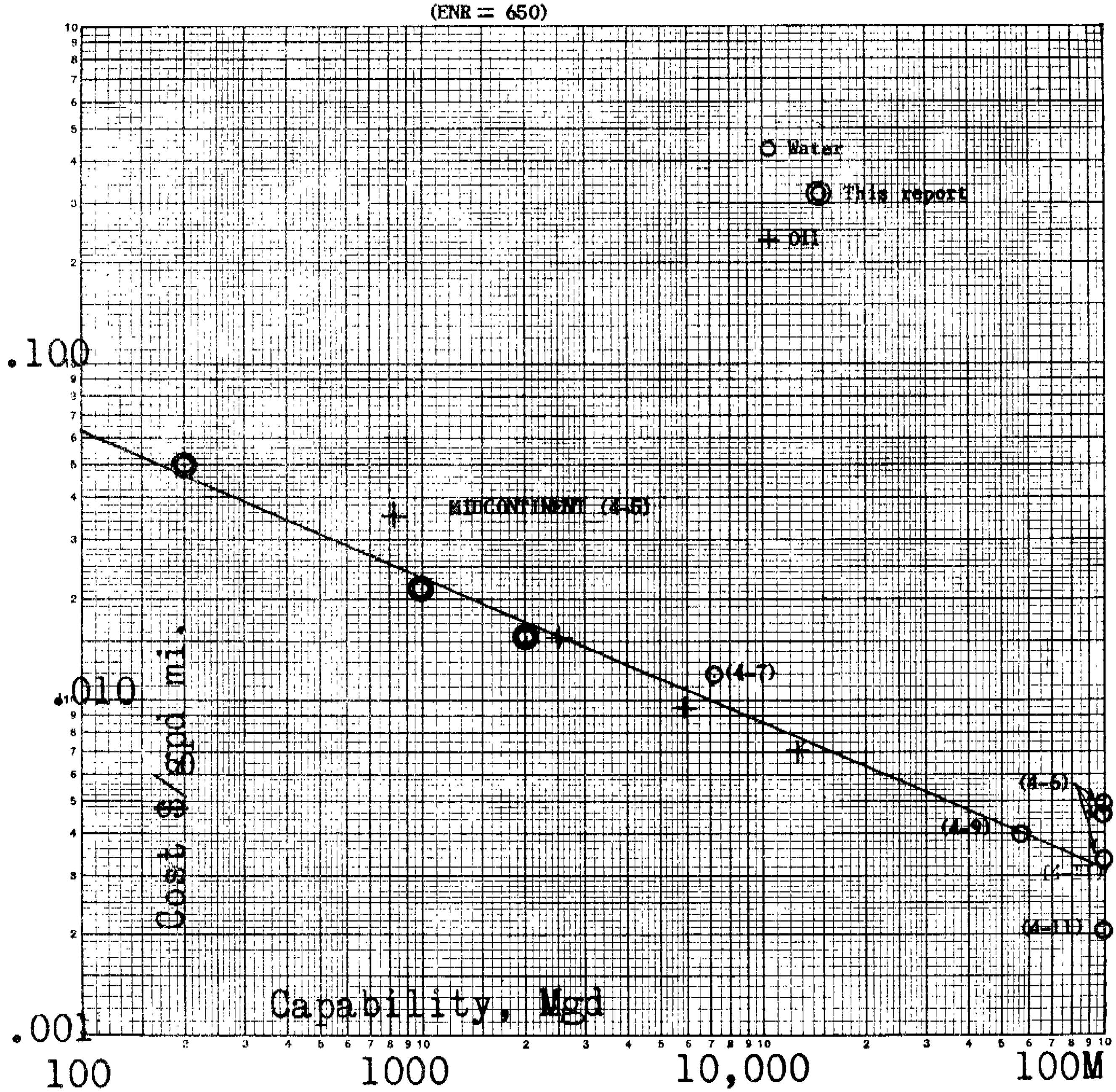

FIGURE 4-4

Pipeline Conveyance Costs, Calculated

The costs of conveyance for our cases are calculated on the following basis.

Reference (4-6) estimates pipeline repairs at \$200 per mile year for a 60 inch water line. Reference (4-15) takes \$50 per mile for oil pipelines 10 years old in good terrain and \$150 in a medium swamps terrain. While \$200 may be a currently accepted engineering figure for water pipelines \$100 is chosen for the present study because if water and brine pipelines are to come into use they will at least have to equal the best oil pipeline practice. This figure gives \$0.375/mile day.

Pump station repairs for an electric station (4-15) are taken at \$1.00/horsepower year equal to \$0.00374/HP day.

Other costs associated with direct operation (4-15) are taken as follows:

Electric power	0.8¢/HP hr. (i.e. \$0.005/KWH at 84% efficiency)
Other costs, 10% of above	0.08¢
	0.88¢/HP hour=\$0.21/HPd

As shown in Chapter 5 depreciation over 40 years, straight line interest at 4%, taxes at 1% and insurance at 1% give operating costs according to the following: \$/gpd x 0.178 ⇒ \$/Mg. Summarizing, the operating costs are as follows:

On horsepower		\$/HPd
Pump station repairs		.0037
Pump energy		.192
Other station costs		.019
	Total	\$.2157/HPd
On pipeline miles		\$/mi. d.
Pipeline repairs		0.374
On capital		\$/Mg
Depreciation, interest taxes, insurance		0.178 x \$/gpd

These calculations are summarized as follows:

Table 4-2

PIPELINE CONVEYANCE COSTS
$/Mg mile

	20	200	1,000	2,000
On capital	.0470	.00892	.00380	.00272
On horsepower	.00375	.00625	.006251	.00174
On pipeline miles	.0187	.00187	.000374	.000187
Total Expense	.0695	.0170	.0107	.00465

Just as it could be noted that the friction head for the 1,000 Mgd case seemed to be high compared to the others, so similarly the expenses based on horsepower seem comparatively high. This probably means that a larger pipe size, say 9" rather than 7 5/8", is indicated as it probably would decrease horsepower costs appreciably more than it would increase capital costs.

Conveyance costs, experienced Experienced pipeline conveyance costs are available for a few water and oil pipelines and a large number of per barrel prices and costs are available for oil pipeline transport between specific points. While not going into all these, Figure 4-5 shows the experience figures for several water pipelines, for a standard estimate oil pipeline and for a couple of presentations of some actual oil transport prices. On the same figure are plotted the calculated data of the previous section.

Again, it is seen that the general trend of the water data encompasses the calculated points. Oil conveyance costs however, appear to be somewhat higher than water conveyance costs at the same capability. However, the slope is approximately the same, as indicated by the Midcontinent Oil line. The reader should not be misled by the data on the Figure labeled "Range of Many" and "Average of 40". The data represent only costs and have no location on the capability axis.

An analysis of why oil conveyance costs should be approximately twice as high as water conveyance costs has not been made, but this should be done in any refinements of this study. No doubt the depreciation rate as well as the interest rate on the oil pipeline is higher than those taken in this study or by the experienced cases for water. Also a return on investment is probably included.

The unit cost seems to be a function of the total distance when the distance is small, but the variation down to 200 miles, at least, is not great. Estimated increases over the unit costs for a 1,000 mile line are (4-5):

PIPELINE CONVEYANCE COSTS

(ENR = 650)

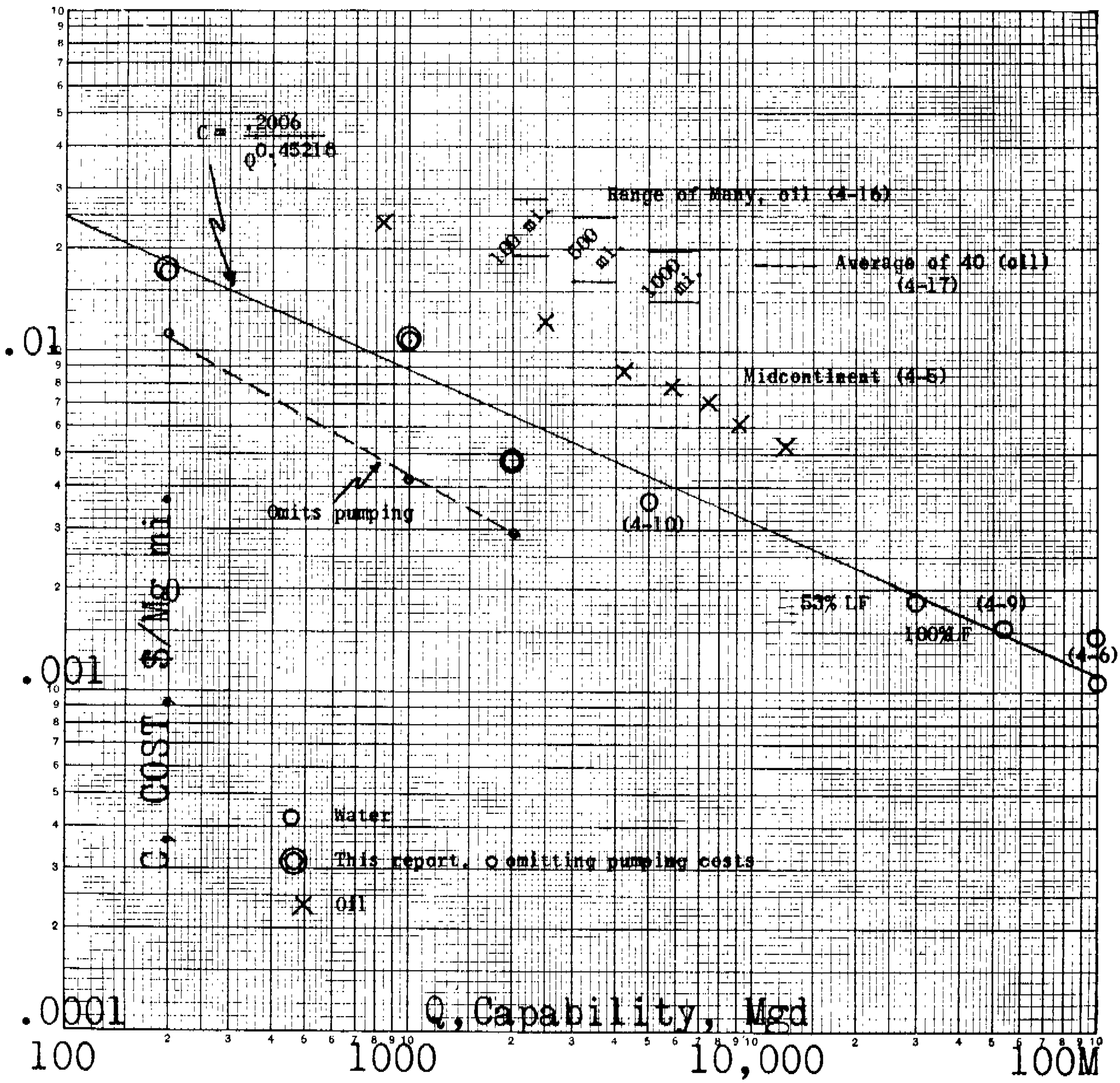

FIGURE 4-5

TABLE 4-3

CONVEYANCE COST INCREASES FOR SHORT HAULS

Miles	1000	800	400	300	200	100 Extrap.	50 Extrap.	10 Extrap.
Increase %	0	1	4.1	7.0	11	18-20	25-35	50-90

In subsequent calculations, in order to eliminate the variations in the calculated value of operating cost, the values used will be those from the smooth curve:

$$C_{CQ} = .2006/Q^{0.45218}$$

which are:

TABLE 4-4

SMOOTH CURVE CONVEYANCE COSTS

Q	20	200	1000	2000	100,000	Mgd
C_{CQ}	.040	.018	.0088	.0064	.0011	\$/Mg mi.

Lowering Pipeline Costs

As these costs will later be shown to be high, a number of approaches should be taken to see if the total cost cannot be reduced. Among these would be the use of canals, which will have to be reserved for a later study. As for pipelines themselves, the most one might hope for is to get by without using any power. This would mean that the driving forces might be whatever difference of elevation was available and the line would be run as a siphon using only an insignificant amount of power to deaereate the line at the high spots. In order to operate as designed, the elevation differences would have to equal the friction head losses now taken from 7-26 feet per thousand feet of line. This of course would be impossible, amounting to a grade of 100 feet or so per mile. However, a comparatively small increase in pipe diameter would considerably decrease the friction loss at a given flow rate, and while this line of reasoning suggests that the pipe sizes chosen are not optimum a more thorough search for the economic optimum will have to be reserved for a later study. For the present we may consider that the increase in size of the line will result in increased cost at least equivalent to the pump station costs and therefore the capital investment of the line operating without pumping will be allowed to remain the same. The only change in the expense items will be the reduction of those based on horsepower to zero which would result in total expenses as follows:

TABLE 4-5

FREE-FLOW PIPELINE CONVEYANCE COSTS

Mgd	20	200	1000	2000
Total expense $/Mg mile	.0320	.0108	.0042	.0029

These figures which are approximately half of the previous figures are also plotted in Figure 4-5. They serve to show incidentally that the discrepancy in the 1,000 Mgd case is probably due to comparatively excessive power requirements due to a too small design diameter. They are the lower limit of costs since a higher pipeline investment than here taken would probably be needed.

* * * * * * * * * * * * * *

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CHAPTER 5

OPERATION: EVAPORATION

Synopsis - OPERATING EXPERIENCE - INVESTMENT COST FOR EVAPORATION FACILITIES: Cost of Earth Moving, Cost of Construction, Cost of Lining , Investment Cost for Evaporation Facilities - OPERATING COSTS FOR EVAPORATION: Non-uniform Annual Evaporation, Seepage Losses BRINE EVAPORATION RATES IN THE U. S.: Rates of Brine Evaporation, Accuracy of Brine-to-Water Ratios, Areas Where Brine Evaporation is Possible, Maximizing Evaporation Rate, Brine Evaporation Correlation - REFERENCES

Synopsis This chapter studies solar evaporation as an intermediate operation in a disposal process, largely for the purpose of reducing the volume of waste necessary to be injected or conveyed. Other forms of evaporation could conceivably be used to accomplish this reduction of volume. However, solar evaporation is generally considered to be the cheapest form in those areas where it is applicable. The results of this chapter show that solar evaporation can be accomplished in the range of \$0.20-.60/Mg, which is considerably below the best costs for any fuel fired evaporation process.

Evaporation or rather distillation also happens to be a conversion process and solar distillation is prominent among these. It may be a little confusing as to why there is suggested an evaporation operation in the disposal process when the conversion process itself may constitute evaporation. The reason, of course, is inherent in the economic fact stated above. Solar evaporation as a conversion process is more expensive than solar evaporation as a disposal operation because the former requires attention to scaling and to collection of the distillate.

In this chapter, after a discussion of operating installations, there is first developed the investment cost for earthen evaporating tanks as a function of capability and evaporation rate. Next, there is developed the operating costs for evaporation under those parameters. Finally, the evaporation rates for brine in various geographical areas are developed for application in the preceding calculation.

OPERATING EXPERIENCE

Operating experience and data with large scale solar evaporation ponds is very limited and practically nothing appears in literature. The Leslie Salt Company, San Francisco operates tidal vats on San Francisco Bay for the evaporation of sea water. Their vat construction and operating conditions are quite different from those which would be encountered in inland evaporating vats for saline water conversion brines (5-1). Bonneville Ltd. has very large acreages of evaporation ponds at Wendover, Utah, evaporating Bonneville Lake brines. A special pond design is used to balance the hydraulic head of concentrated brine with that of fresh water in an outside ditch (5-2). This cuts down on seepage. The Anglo-Lautara Nitrate Corporation, Pedro de val Devia, Chile, evaporates brines and leach liquors from nitrate mining (5-2). They have developed, against the high earthquake frequency in that region a method of making ponds self-healing. The particular ore they are using consists of brecciated ryholite. The leached residue is used for evaporation embankments. If quick lime is mixed with the embankment material the $MgCl_2$ in the seeping liquors reacts with the lime and precipitates the gel which fills the pores. The Antofagasta & Tarapaca Nitrate Corporation in Chile at one time used a figure 8 railroad track in the evaporating pond (5-2). A railroad engine and attached pump car ran around the track spraying brine for evaporation. The salts, when they built up to a height of about a foot, were harvested by bulldozer. The Palestine Potash Company operates large evaporating ponds at their plant on the Dead Sea (5-3).

Because of the remoteness of these installations and the lack of information in the published literature, very little attempt has been made to utilize them in this study. More detailed studies, however, should include detailed studies in the operating experience at the above and other installations.

INVESTMENT COST FOR EARTHEN TANKS

Cost of Earth Moving The literature survey did not reveal any estimates of the cost of earthen vats for solar evaporation. Accordingly it was necessary to calculate this using standard estimating methods (5-4). The construction is assumed to be done with rubber tired scrapers, operating at an average haul distance of 1500 feet. The cost will be as follows:

	$/cubic yard
Rubber tired scraper	0.186
Shaping, compacting, sprinkling	0.076
Direct Cost	0.262
Overhead, 10% x .262	0.026
Engineering, 7% x .262	0.018
Interest during construction, 3 months @ 4%	0.001
Contingencies, 5% x .262	0.013
	0.320
Profit 10% x 320	0.032
Unit Cost/cu. yd.	0.352

This figure is roughly confirmed by independent estimates by a construction firm of $0.35-.50/cu. yd. (5-5).

Cost of Construction

It is assumed that the dike will be in the shape of an equilateral triangle, approximately 20 feet at the base and truncated at 5 foot altitude by a dike top 5 feet wide. The area of this cross section will be 6.25 cubic yards/yard of dike. This is probably small as a dike for an evaporating vat. A chemical company having considerable experience with evaporating vats uses dikes 10 feet across the top instead of five feet, having a cross section of 7.42 cubic yards/yard of dike. Leslie Salt Company, constructing dikes under quite different circumstanceson swampy tidal marsh, uses dikes 12 feet across the top, having a cross section of 10.1 cubic yards/yard of dike (5-6). As will be seen, the cost of vat construction, that is dike construction, is of significance only for unlined tanks and of importance only in the smaller sizes of these. An average cost of land is taken at $100/acre.

Cost of Lining

Unfortunately, it seems unlikely that unlined earthen tanks will be suitable for salt water service. Some earthen reservoirs for fresh water or waste water not containing salts have taken advantage of underlying strata of impervious clay to form an almost seepage proof bottom. Seepage that occurs laterally on top of this strata can be taken care of by seepage ditches, the flow in which is pumped back into the tank. Concentrated salt water however has the effect of flocculating (shrinking) clays. Clays, either as solid clay layers or as clay admixtures in the interstices of other formations, gain their impervious properties from their swelling properties. It is well know that clays will not swell in concentrated salt water. The Leslie Salt experience (5-6) is expressed as follows:

> "The soil in the salt producing area is of a dense clay consistency and tight enough to keep leekage to a minimum. Even this soil at first is not tight enough to hold the denser brine, and it is only after several years of continuous flooding of an area that enough brine can be held to start making salt. The natural precipitation of calcium sulfate is believed to assist in gradually sealing pond bottoms".

Of the same tenor is the following (5-7) relating to pits for oil field brines

> "Much of this damage is as a result of flocculation of soil particles by the sodium ion. While salt pits are still relatively young the clumping of soil particles leaves tiny crevices between the grains of soil and these fill with water and brine and thus keeping the soil from packing. This newly flocculated soil comprises a virtual quicksand into which a man's foot can sink for a foot or more. Later, when the pit is older and is dried out a few times, the flocculated soil packs and becomes almost as hard and firm as concrete. Even after the salt has leached from the surface of such land the soil is too compacted to permit the entrance of plant roots for many years."

Also the following (5-8):

> "The injury that salt does to soil is mainly the peptization or dispersal of the soil particles such that puddling and induration takes place. A salt puddled soil assumes a porous condition as it dries and becomes hard after which it is very permeable to air...High concentrations of sodium chloride will also flocculate the soil particles...Because brine from oil wells contains such a high percentage of sodium chloride, soil colloids in the salt water pits are flocculated increasing the effective pore size in the soil and thereby permitting more water movement both horizontally and vertically..."

Also (5-9):

> "[Salt water] will not be confined in earthen pits. Action of salt on soil is such that the water seeps freely through earthen dams...Salt tends to flocculate soils and renders earthen ponds inefficient for impounding salt water."

Also (5-10) it is known that the permeability of oil reservoir formation is effected by the concentration of salt in the waters. For example, if a reservoir core is tested for permeability, it will show a permeability for fresh water much less than the permeability for air. However, if salt water is substituted for fresh water in the permeability measurement then the permeability rises again. The core originally was in equilibrium with connate salt water. The clays were flocculated, that is contracted, and allowed an open pore space for air passage. When fresh water was used the clays swelled and plugged the pores. When salt water is used the clays again were flocculated and opened the pores.

Some of the above excerpts contain some interesting apparent contradictions. It is indicated that salt water makes the soils porous so that the pits will not hold water. At the same time it is indicated that later, possibly after drying out a few times, the soils become exceedingly hard and dense, so that roots cannot penetrate them. It would almost seem that a soil which could be thus described ought to make an impervious container for salt water. Consider also the statement (5-7):

> "The flocculated land surface is hard and barren, draining rainfall with extreme rapidity and contributing materially to flooding."

An additional suggestion that the salt induced porosity of the pits may be <u>self-healing</u> as with the Leslie Salt pits comes from reference (5-7).

> "The salt then flocculates the soil [in the dikes] until numerous tiny crevices form and leak salt water to the surface of the ground. In a year or so flocculation clumps the soil beneath the ground level and the pit leaks into the ground at a constantly increasing rate rather than onto the surface of the ground. In addition to soluble materials the brine as brought from

> the depths of the earth contains reduced substances, soluble only in their reduced state. On exposure to the the air these compounds oxidize and precipitate to form a sludge on the bottom of the pits. Unless removed these materials will eventually seal the pores resulting from flocculation."

The possibility that the permeability of these salt water holding pits is only temporary and is self-curing or that brine retention may be brought about by some sequence of operations is worthy of some technical investigation. However, such is beyond the scope of the present project and in any event the main intention of the writers of the above excerpts is to convey the thought that salt water will seep out of unlined pits.

The cost of lining with 1½-2 inches of unreinforced concrete is taken at $1.30 per square yard. Reinforced concrete and shotcrete linings are more expensive; asphalt linings of some types are somewhat cheaper but last only 8-10 years. Concrete linings have an average serviceable life of about 40 years when carrying fresh water. Some linings are known to have been in service for 60 years and more (5-11).

This study did not develop any experience figures for the life of concrete used in concentrated brine vats and the subject needs a more thorough investigation than can be given here. Salt brine will apparently have little chemical effect on the concrete itself. The major action comes in areas subject to alternate wetting and drying through the crystallization of salts in the pores of the concrete. This may be minimized, for example, in sea water structures by proper proportioning, careful placement and careful curing (5-12). Of pertinence for the present study is the recommendation that concrete for brine service contain six or possibly as many as seven sacks of cement per cubic yard compared with the four or five ordinarily used. Also, the aggregate should be adjusted to contain a certain portion of fines in order to give high density (i.e. low permeability) (5-13) (5-14).

In addition, it is possible to use various protective treatments, particularly magnesium fluosilicate or zinc fluosilicate applications, various drying oils, and Cumar resins. The cost of the protective treatments has not been investigated in this study. The cost of the higher cement ratio would be approximately $1.50 per cubic yard, or about $0.06 per square yard of 1½ inch lining. This would add approximately 5% to the estimated unit cost taken -- but this adjustment has not been made in this report.

In the direction of cost reduction there is now under development a method of lining reservoirs with soil-cement which has long been used for paving purposes. The bottoms of a few large reservoirs have been lined with soil-cement using the same methods of construction as used in paving. This will cost in the neighborhood of 60% of the cost of installed concrete lining; here taken as $0.80/sq. yd. (5-11) (5-13).

The results of calculations on the above data are indicated in the following table.

TABLE 5-1

PER ACRE COST OF TANKS

Water Surface, Acres	1	5	10	50	100	1000
Yards square	69.5	155	220	493	695	2200
Land cost, $/acre	100	100	100	100	100	100
Dike cost, $/acre	612	273	194	86.50	61.20	19
Total Cost, $/acre,						
Unlined	712	373	294	186	161	119
Concrete lined	7012	6673	6594	6486	6461	6419
Soil-cement lined	4572	4233	4154	4046	4021	3979

Interpolation curves for these costs are given in Figure 5-1.

Investment Cost for Evaporation Facilities

Under the conditions chosen in the preceding the investment cost per gpd capability may be calculated as follows:

$$A_t = \frac{13.44\ Q}{E_t}$$

where

A_t = tank area required, acres

E_t = evaporation-minus-precipitation from tank, "/year

Q = capability, Mgd

The acres required will be:

	20"	40"	60"
20 Mgd	13.4	6.70	4.47
200 Mgd	134	67	44.7
2000 Mgd	1340	670	447

COST OF EARTHEN TANKS

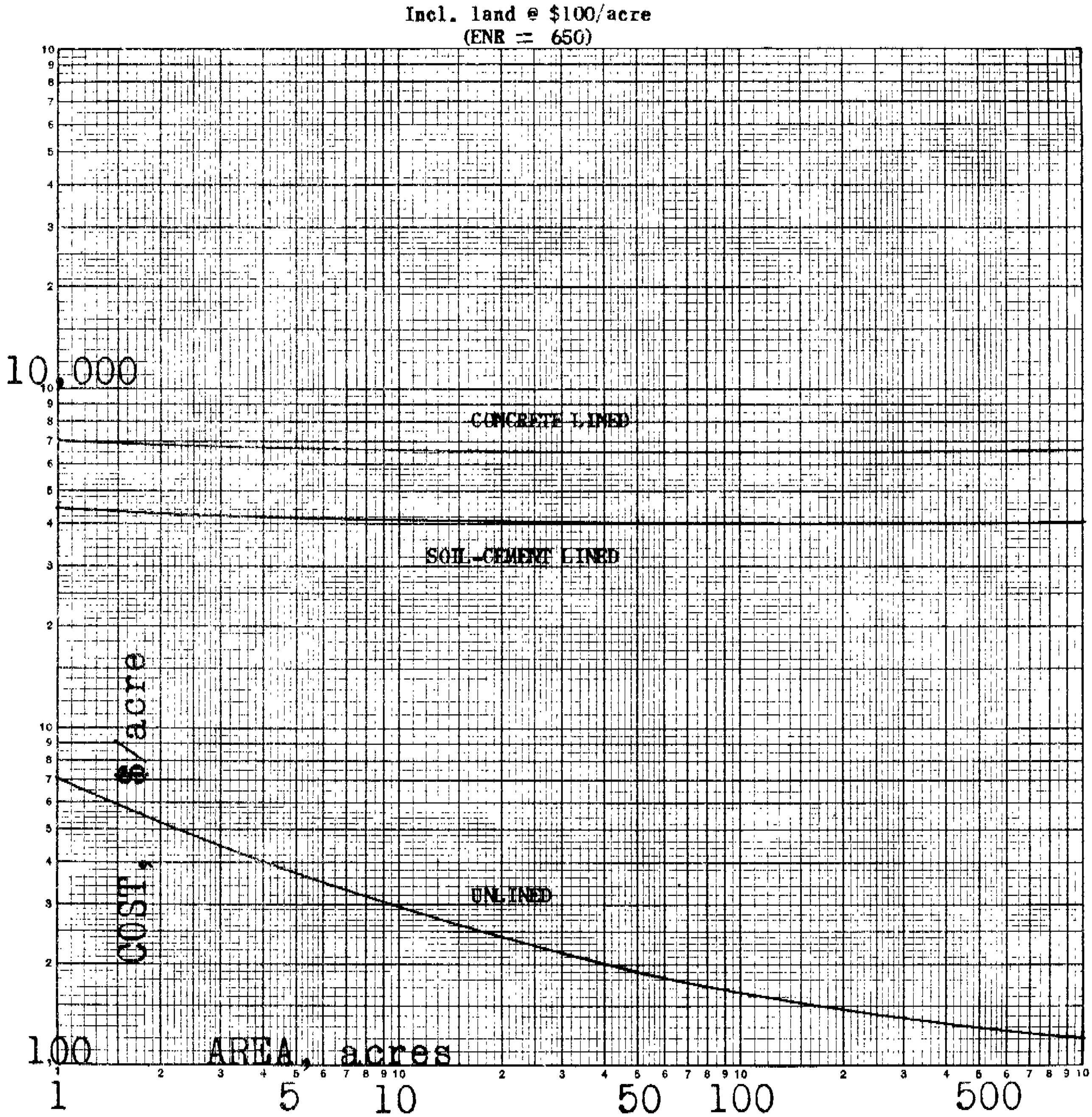


FIGURE 5-1

The tank cost, previously arrived at, conforms to equations as follows:

$$\text{Unlined, dollars} = 100\ A_t + 612\ (A_t)^{1/2}$$

$$\text{Soil-cement, dollars} = 3960\ A_t + 612\ (A_t)^{1/2}$$

$$\text{Concrete, dollars} = 6400\ A_t + 612\ (A_t)^{1/2}$$

where 100, 3960, 6400 are the per acre cost of land and lining = l_u, l_s, l_c resp.

The tank cost divided by the capability, 1000 Q, gives the cost per unit capability. This becomes

$$\$/\text{gpd} = 0.01344\ \frac{l_{u,\ s,\ or\ c}}{E_t} + \frac{2.25}{(QE_t)^{1/2}}$$

or under the values of l taken:

$$\$/\text{gpd (unlined)} = \frac{1.34}{E_t} + \frac{2.25}{(QE_t)^{1/2}}$$

$$\text{(Soil-cement)} = \frac{53.4}{E_t} + \frac{2.25}{(QE_t)^{1/2}}$$

$$\text{(Concrete)} = \frac{86.0}{E_t} + \frac{2.25}{(QE_t)^{1/2}}$$

Figures resulting from these equations are shown in Table 5-2.

TABLE 5-2

INVESTMENT COSTS FOR EVAPORATING TANKS
$/gpd

Evaporation, in./yr.	1	10	50	100
Unlined				
20	1.84	.293	.0980	.0638
200	1.50	.184	.0493	.0293
2000	1.39	.149	.0339	.0184
Soil-cement				
20	53.9	5.50	1.139	.588
200	53.6	5.39	1.090	.549
2000	53.4	5.36	1.075	.539
Concrete				
20	86.5	8.76	1.79	.914
200	86.2	8.65	1.74	.876
2000	86.0	8.62	1.73	.865

When the waste consists of concentrated brine, a correction factor must be applied to these figures to allow for the salt content. This factor is as follows, assuming the salt has the properties of NaCl.

Concentration ppm	Gal. water / Gal. waste
5,000	.9975
20,000	.9922
80,000	.9709
160,000	.9372
200,000	.9178
260,000	.8852

Thus from saturated brine the gallons of water to be evaporated is only 88.5% of the gallons of waste. The accuracy of our cost calculations is such that this 11.5% correction may be neglected.

OPERATING COSTS FOR EVAPORATION

Experience figures for operating costs of earthen tanks, evaporating or storage, were not developed in the course of this study. Although a number of installations have such tanks, the operating costs are either included with other general plant and maintenance costs or else contain items extraneous to our purposes such as collection and pumping costs. The operating costs would be composed almost entirely of depreciation and maintenance.

The closest approach to a figure on maintenance costs may be obtained from reference (5-15) which indicates that maintenance costs at 1950 EN cost index are $6.00 annually per hundred foot of a concrete lined canal of capacity 1,000 cfs. The same reference indicates that a 1,000 cfs canal of 30 foot bottom width would have 7.4 square yards of lining per linear foot of canal. Combining these figures we obtain an annual maintenance cost of $39.20 per acre of lining which is $0.107/acre day. Maintenance costs on unlined canals are cited at $10.50 instead of $6.00 but most of the maintenance for unlined canals consists of eliminating weeds. Since weeds will not grow in brine ponds it can be assumed that maintenance costs of unlined tanks will be the same as for concrete lined. It is likely that the per acre cost of maintenance should drop as the total acreage of tanks increases. However, for simplicity, we have used a constant per acre day maintenance cost.

The number of acres required may be calculated by

$$\text{acres required per Mgd} = \frac{13.44}{E_t}$$

Maintenance costs at the $0.107 figure are:

$$\text{maintenance cost \$/Mg} = \frac{1.44}{E_t}$$

Note that maintenance cost depends only on evaporation rate.

Depreciation plus interest on depreciated balance is not available in reference (4-12) for the 40 year term. Accordingly the interest is calculated for simplicity on the straight line basis rather than on the depreciated balance basis. The operating costs other than maintenance thus taken are:

Depreciation - 40 years		2.5%
Interest - 40 years, 4% straight line		2.0%
Taxes		1.0%
Insurance		1.0%
	TOTAL	6.5% per year on investment cost.

The cost of these items per thousand gallons may be calculated as:

$\$/gpd \times 0.178 = \$/Mg$

The combination of all the above data into a total cost is contained in Table 5-3.

TABLE 5-3

OPERATING COST, EVAPORATION
$/Mg

	Unlined	Soil-Cement	Concrete
Evaporation, 10 in/yr.			
20 Mgd	.196	1.122	1.700
200 "	.177	1.103	1.681
2000 "	.171	1.097	1.675
Evaporation 40 in./yr.			
20 Mgd.	.056	.2876	.432
200 "	.046	.2780	.422
2000 "	.043	.2749	.419
Evaporation 100 in./yr.			
20 Mgd	.0258	.1184	.1762
200 "	.0196	.1122	.1700
2000 "	.0177	.1103	.1681

Combining with the equations already developed for investment costs, (page 5-8):

$$\text{Operating cost, \$/Mg, unlined} = \frac{1.68}{E_t} + \frac{0.400}{(QE_t)^{1/2}}$$

$$\text{Soil-Cement} = \frac{10.94}{E_t} + \frac{0.400}{(QE_t)^{1/2}}$$

$$\text{Concrete} = \frac{16.72}{E_t} + \frac{0.400}{(QE_t)^{1/2}}$$

Interpolation curves based on these equations are shown in Figure 5-2.

Nonuniform Annual Evaporation

The above analysis assumes the simple case that net evaporation is uniformly distributed from year to year. Consider the tanks designed for 20 inch and 60 inch net evaporation. In the 20 inch case enough brine is being fed to the ponds so that if no net evaporation occurred the pond level would build up at the rate of 20 inches per year. The dikes are five feet high and allowing one foot of freeboard there remains four feet of space to contain the accumulated brine. This means that such an installation could safely weather two and a half years of zero net evaporation without overflowing the ponds. Indeed the evaporation rate under normal pond operation would probably be found to exceed 20 inches a year since the evaporation rate increases as the layer of evaporating brine becomes shallow. The standard evaporation rates used in the next section refer to deep lakes with little influence from shallows.

On the other hand, vats designed for 60 inch net evaporation would accumulate 60 inches per year if the net evaporation dropped to zero. The frequency of such an occurrence where the net evaporation averages 60 inches per year is, of course, very small, yet even one year of 12 inch net evaporation would fill the tanks to the freeboard. Deeper tanks would be required in order to provide storage for this accumulated brine until years of higher than average evaporation could take care of it.

A statistical analysis of the frequency of low evaporation years would be required to arrive at a design depth for a calculated risk in each case. Such a statistical analysis is not possible within the scope of the present study. On the other hand, deepening of the tanks does not add a great deal percentage-wise to the tank cost for the soil-cement and concrete lined construction for in those cases by far the greatest part of the cost consists of the lining, the cost of which does not vary significantly with depth.

Seepage Losses

The foregoing calculations do not take into account seepage losses from the three types of tank structures. Seepage losses will have two effects, one, the pollution of the ground water or two, the expense of collecting, sumping and repumping the seeped liquor. The latter might

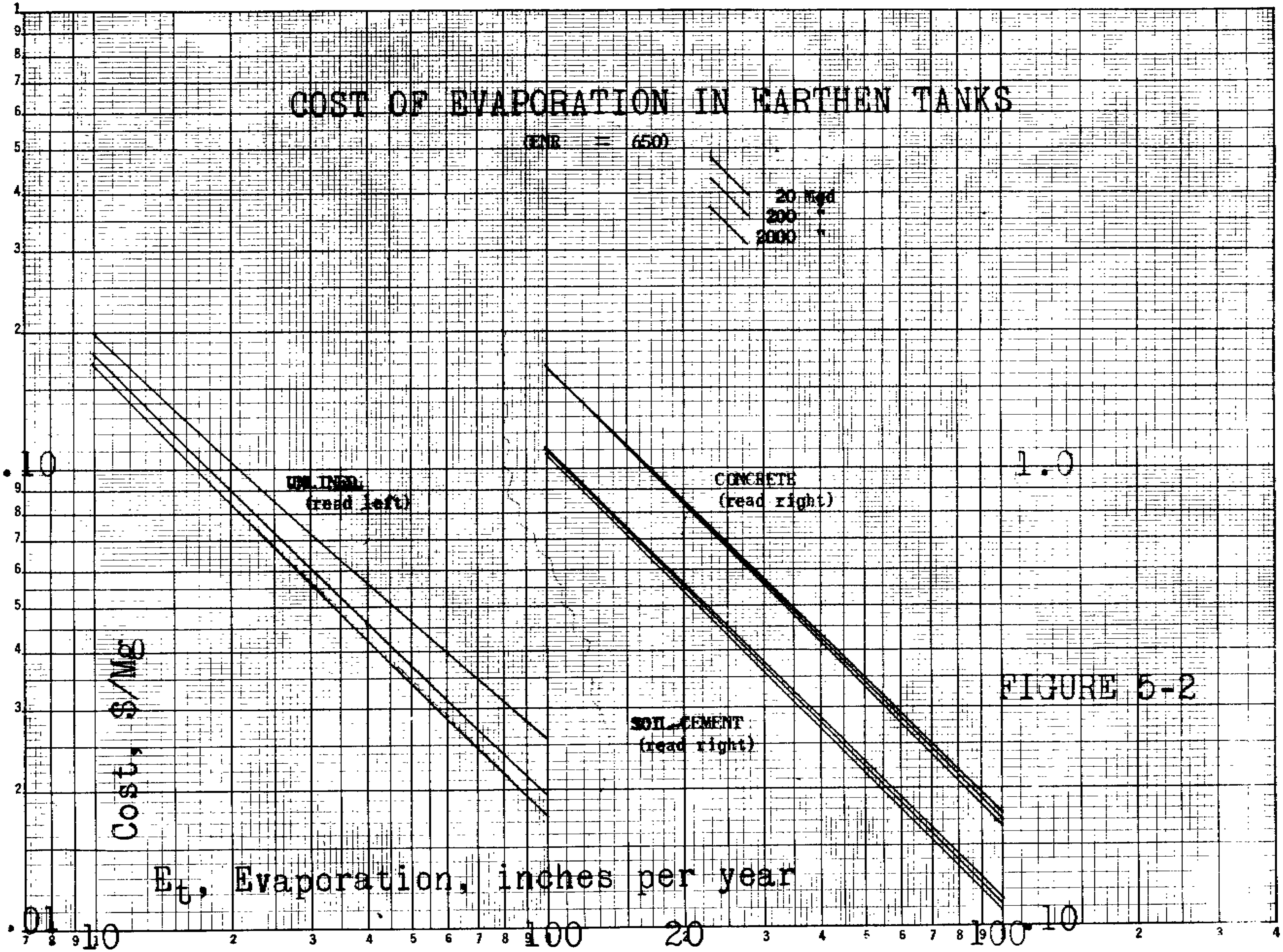

COST OF EVAPORATION IN EARTHEN TANKS
(ENR = 6500)
20 Mgd
200 "
2000 "
UNLINED
(read left)
CONCRETE
(read right)
SOIL-CEMENT
(read right)
Cost, $/Mg
E_t, Evaporation, inches per year
.01
10
100
20
100
.10
1.0
.10

FIGURE 5-2

be done by means of underdrains laid at the time of construction of the reservoir and run to a central sump say one for every 100 acres of tanks from whence it is repumped into the tank. A little thought will reveal that the efficiency of underdrains is related to the relative permeability of the tank bottom as compared with the subsoil through which the seepage occurs. If the tank bottom is fairly pervious such as in unlined tanks underdrains might collect a good deal of the seepage but they could not collect all of it unless they cover the entire projected area of the tank and were absolutely impermeable. Underdrains will collect a smaller percentage of the seepage as:

the permeability of the tank bottom decreases
the permeability of the subsoil increases
the per cent of the projected area intercepted by them decreases, and
the permeability of their own materials of construction increases.

Some of these relations can be visualized if one considers underdrains under a concrete lined reservoir. Even if the underdrains cover 100% of the projected area they will collect 0% of the seepage if their permeability (feet per day) is the same as that of the concrete lining. To the extent that it is possible to have such an impermeable material, then it would probably be better to make the reservoir lining out of that material in the first place. Considerations such as this indicate that underdrains are only of value when there is a considerable amount of seepage and that they cannot collect a very great proportion of that.

A different situation arises when the reservoir, though the bottom be permeable, rests upon an "impermeable" clay layer or the like. In that case, seepage from the permeable reservoir bottom would be downward to the "impermeable" clay layer and then laterally. In that case interception ditches surrounding the area and reaching into the clay layer will intercept the seepage satisfactorily for the purpose intended. However, it is to be recognized that even in this case downward seepage through the "impermeable" clay layer is still continuing and the seepage of the entire system in feet per day will equal the seepage of the clay layer.

In the present study we are ponding a waste that has no self purification properties and we intend to do it over a period of at least scores of years. Accordingly we are seeking a seepage rate which must be the absolute minimum. This turns out to be an elusive figure.

Considerable data exist in the literature on the seepage rates through various types of soils but these are largely in the region of water movement rather than water containing. While a complete study has not been made in this preliminary survey, data published in Reference (5-15) on seepage losses from lined and unlined irrigation canals has been considered. Values found are: gunnite .03, cu. ft./sq. ft. day, average of two values; soil-cement .09, average of 7 values; concrete .07, one value. There is considerable variability among the data. Some measurements on soil-cement lining for example gave the same seepage values as for heavily compacted earth linings. The best values noted in any case are .03 given for two out of two gunnite measurements and two out of seven soil-cement measurements. Thus, the very best seepage measurements available correspond to 130 inches per year of seepage loss or about 10 Mgd/acre.

That this seepage rate is startling may be realized when it is recalled that we are intending to evaporate 20 Mgd in the 40-60 inches per year evaporation region in approximately five acres of tanks. According to the above seepage figures 5 acres of tanks of the very best possible construction namely concrete lined, would lose the waste by seepage about two and one half times as fast as it was put in. Obviously, the subject needs further study.

A preliminary analysis suggests that the losses cited above are largely evaporation losses rather than seepage losses. Reference (5-16) presents the same data as Reference (5-15). The text indicates that the measurements of interest were made by the ponding method, that is, blocking off a section of an irrigation canal and measuring the drop in the water surface -- but the text makes no mention of correcting for evaporation. The text of Reference (5-15) which largely duplicates Reference (5-16) states that the tests cited were made during the 1949 irrigation season by constructing earth dikes across the Ft. Laramie Canal and that "evaporation data taken during the test proved to have a negligible effect on the rates". This statement may be subject to questioning. .03 feet per day corresponds to about 11 inches per month. The measurements were made in the irrigation season, presumably summer, when an area having a 60 inch per year evaporation might easily show an eleven inch per month evaporation. Thus, it is possible that all of the observed drop in water level could have come from the normal evaporation to be expected. Seepage rates are calculated in terms of square feet of wetted area whereas evaporation is based on surface area which would usually be smaller. Nevertheless it is difficult to see how under normal circumstances the evaporation could have been negligible compared to the measured water drop.

While .03 feet per day may be considered a satisfactory seepage loss from an irrigation canal the calculations above show that it is excessive for a waste evaporating tank. The importance lies in the pollution aspect rather than in the cost aspect. Calculated using some of the concepts and data of Chapter 4 the cost of fixed charges and other operating expenses for sump pumps operating against a 10 foot head for 100 acre vats having .03 seepage would amount to

$$\frac{.0794}{E_t} \text{ , \$/Mg of waste evaporated.}$$

At an annual evaporation of 10 inches this would amount to $.008/Mg, at 100 inches $.0008/Mg. For most purposes these are negligible figures and thus are not included in evaporation costs cited above.

But on the basis of pollutinn it is recommended that a thorough study be made of seepage losses from reservoirs of various construction, methods of reducing them, and methods of collecting that irreducible minimum of seeped liquor.

BRINE EVAPORATION RATES IN THE U. S.

Rates of Brine Evaporation

The knowledge of evaporation from free water surfaces has recently undergone a significant advance as a result of cooperative studies by the U. S. Geological Survey, the Navy Department, The Bureau of Reclamation, and the Weather Bureau (5-17). There it is shown that the rate of evaporation from a standard

Weather Bureau Class A evaporating pan is proportional to the difference between the saturated vapor pressure of the water and the partial pressure of water vapor in the air. It was later shown (5-18) that a better fit is obtained when the rate is made proportional to the 0.88 power of the above difference; but the difference between the two does not affect the calculations of the present report. Under certain idealized conditions the application of a coefficient to the measured pan evaporation gives the evaporation observed from large natural bodies of water. This coefficient varies with the type of pan. For the Weather Bureau Class A pan it is 0.70. For the Bureau of Plant Industry pan it is 0.91. The remaining differences from ideality are taken into account by correction terms applied beyond the application of the coefficient. These differences from ideality also cancel out in the calculations of this report because they are virtually the same for brine as for water.

The evaporation of brine under the same meteorological conditions will be different from that for water because the saturated vapor pressure of the brine is lower than for water. For that reason, the evaporation will be less. Compensating for this lowering however, is the fact that since the evaporation is less the temperature of the surface layers will be higher. The quite tedious calculations necessary to relate pan evaporation of brine to pan evaporation of water have been made by Harbeck (5-19) for one set of conditions. The resulting ratios E_{brine}/E_{water} for salt concentrations of 260,000 ppm and 150,000 ppm are shown in Figure 5-3 where

E_{brine} = evaporation of brine from Weather Bureau Class A pan, inches per year.

E_{water} = evaporation of water from Weather Bureau Class A pan, inches per year.

While strictly these ratios should be calculated for the existing values of the other parameters (humidity, temperature of the air, difference in temperature between air and water surface, and pressure) the calculations would be too lengthy for this exploratory study and it is instead assumed that the Harbeck ratios apply to all conditions of interest.

Accuracy of Brine-to-Water Ratios

The accuracy of the Harbeck ratios has not been adequately tested against a wide range of experimental data, for as a matter of fact surprisingly little experimental data on solar brine evaporation is available. Harbeck was apparently able to find only one measurement against which to check his calculations (5-20). Recently another study has been undertaken in Israel (5-3) in which it is shown that evaporation of saturated salt brines from special pans is proportional to the vapor pressure difference between brine and air as is the case with water. The proportionality constant obtained was about 0.88 compared to a constant of 1.0 obtained by Rowher for a small pan with water. Rowher's pan coefficient (to obtain lake evaporation from pan evaporation) was 0.771 compared to the Class A Weather Bureau pan coefficient of 0.70. Combining these coefficients and ratio results in a brine-to-water ratio of 0.80 for evaporation from the Israel salt pans compared with evaporation from standard Weather Bureau water pans.

$$E_{Israel} = 0.80\ E_{WB}$$

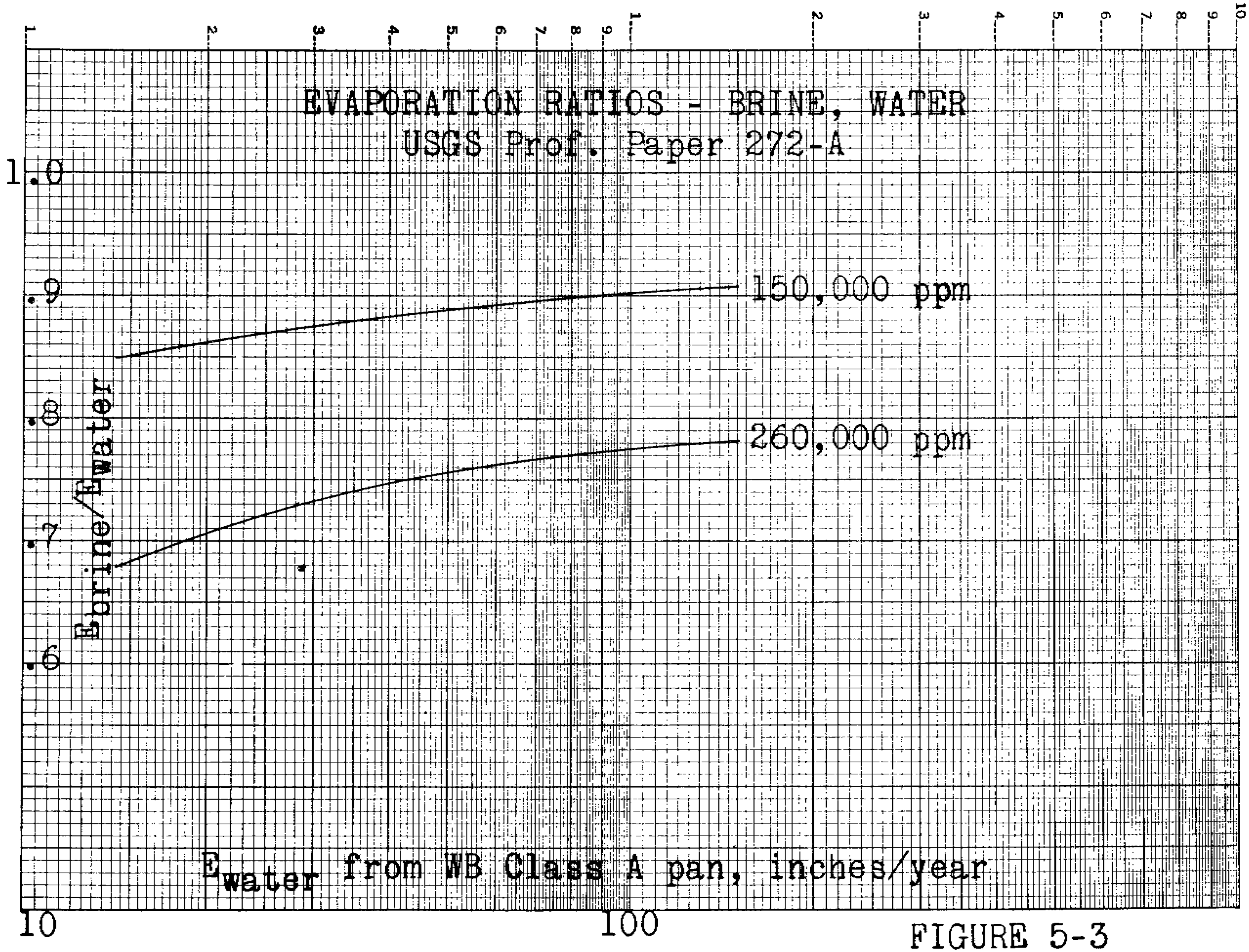

EVAPORATION RATIOS - BRINE, WATER
USGS Prof. Paper 272-A
1.0
.9
.8
.7
.6
150,000 ppm
260,000 ppm
Ebrine/Ewater
Ewater from WB Class A pan, inches/year
10
100

FIGURE 5-3

Unfortunately the pan-to-lake coefficient for the Israel pan is not given and thus the ratio 0.80 includes not only the brine to water ratio but also the Israel to Weather Bureau pan coefficient. If the Israel pan coefficient is .70 then the brine-to-water ratio will be .80. If the Israel pan coefficient is more nearly like the BPI pan coefficient, say .90, then the salt-to-water ratio will be 0.62. However, since the Israel pan was of quite special construction it is probably idle to speculate on its coefficient. The best conclusion that it is possible to draw from the above information is that probably the Israel evaporation experiments are not greatly at variance with the Harbeck ratios.

However, quite to the contrary and quite striking is the statement in Reference (5-6)

> "Evaporation rate decreases as the strength of the brine increases until at the bittern stage the rate is about 30 per cent that of fresh water. Evaporation rate is enhanced by the increased heat adsorption from algae and red organism growth in the brine".

This indicates a brine-to-water ratio of 0.30 even under enhanced heat adsorption conditions and such data does contradict the Harbeck ratios. 0.30 incidentally is the ratio that would be obtained under average conditions if the reduced vapor pressure effect alone played a part without the compensating influence of increased temperature in the surface layer. Possibly the Leslie Salt brines contaminated as they are may also contain organic materials which may form evaporation-retarding monomolecular films.

At any rate it is obvious from the above that the solar evaporation of brine is not a thoroughly investigated subject and that any figures used must be open to some suspicion. In the present study we will use the Harbeck ratios since the theoretical reasoning on which these ratios are based has been thoroughly tested in all parameters in the case of fresh water, and the mechanism by which brine evaporation differs from water evaporation is thought to be thoroughly understood. Nevertheless additional experimental work should be undertaken to obtain design factors for solar brine evaporation.

Areas Where Brine Evaporation is Possible

Using the Harbeck ratios, brine evaporation rates may be calculated from pan evaporation rates for water observed in standard evaporation stations of the Weather Bureau and other agencies (5-21). Table 5-4 shows the results of the following types of calculation, using the following symbols:

E_0 = gross evaporation from water pond surface inches/year

P = precipitation inches/year

E_0-P = net evaporation from water pond surface (evaporation minus precipitation) inches/year.

E_{150} = gross evaporation from brine pond of 150,000 ppm, inches/year

E_{260} = gross evaporation from brine pond of 260,000 ppm, inches/year.

TABLE 5-4

BRINE EVAPORATION RATES IN U. S.

State	Station	Ppt'n. in./yr. (5-22)	E_0 in./yr.	E_0-P	E_{150}-P	E_{260}-P
Arkansas						
	Stuttgart	50.37	35.5	-14.9	-18.8	-23.6
	Hope	49.50	41.5	- 8.0	-12.5	-18.0
	Russelville	46.90	37.6	- 9.3	-13.5	-18.5
Oklahoma						
	Norman	33.02	43.4	10.4	5.6	0
Texas						
	Ysleta	8.56	69.4	60.8	53.4	44.0
	Austin	34.43	47.0	12.6	7.6	1.4
	Beeville	30.8	53.5	22.7	16.7	10.3
	College Station	38.66	44.7	6.0	1.6	- 4.7
	Denison	33.51	51.9	18.4	12.7	6.2
	Spur	21.30	57.6	36.3	30.2	22.7
New Mexico						
	Elephant Butte	9.41	72.5	63.1	55.6	46.6
Colorado						
	Pueblo	11.54	53.6	42.1	36.5	29.6
Utah						
	Lehi	12.68	45.6	32.9	27.8	21.9
Arizona						
	Yuma	3.58	62.0	58.4	52.0	44.4
	Tucson	11.16	58.0	46.8	40.3	33.3
	Mesa	13.53	56.4	42.9	36.8	29.7
California						
	Davis	16.43	46.3	29.9	24.5	19.4
	Fall River Mills	17.14	43.4	26.3	21.5	15.9
	Lodi	17.10	48.4	31.3	26.1	19.8
	Oakdale	14.08	55.0	40.9	34.9	28.2
	Chula Vista	ca 10.1	43.5	33.4	28.7	23.1
Nevada						
	Boulder City	ca 5	84.4	79.4	71.0	60.5

E_0 is obtained by applying the corresponding coefficients to the pan evaporation listed in Reference (5-21). E_{150} and E_{260} are obtained by applying the appropriate Harbeck coefficients to E_0. As it happens, over the entire range of E_0 covered in the 21 stations in Table 5-4 the Harbeck ratios vary very little from their average values (for the 21 stations) of 0.765 for the 260,000 ppm brine and 0.892 for the 150,000 ppm brine.

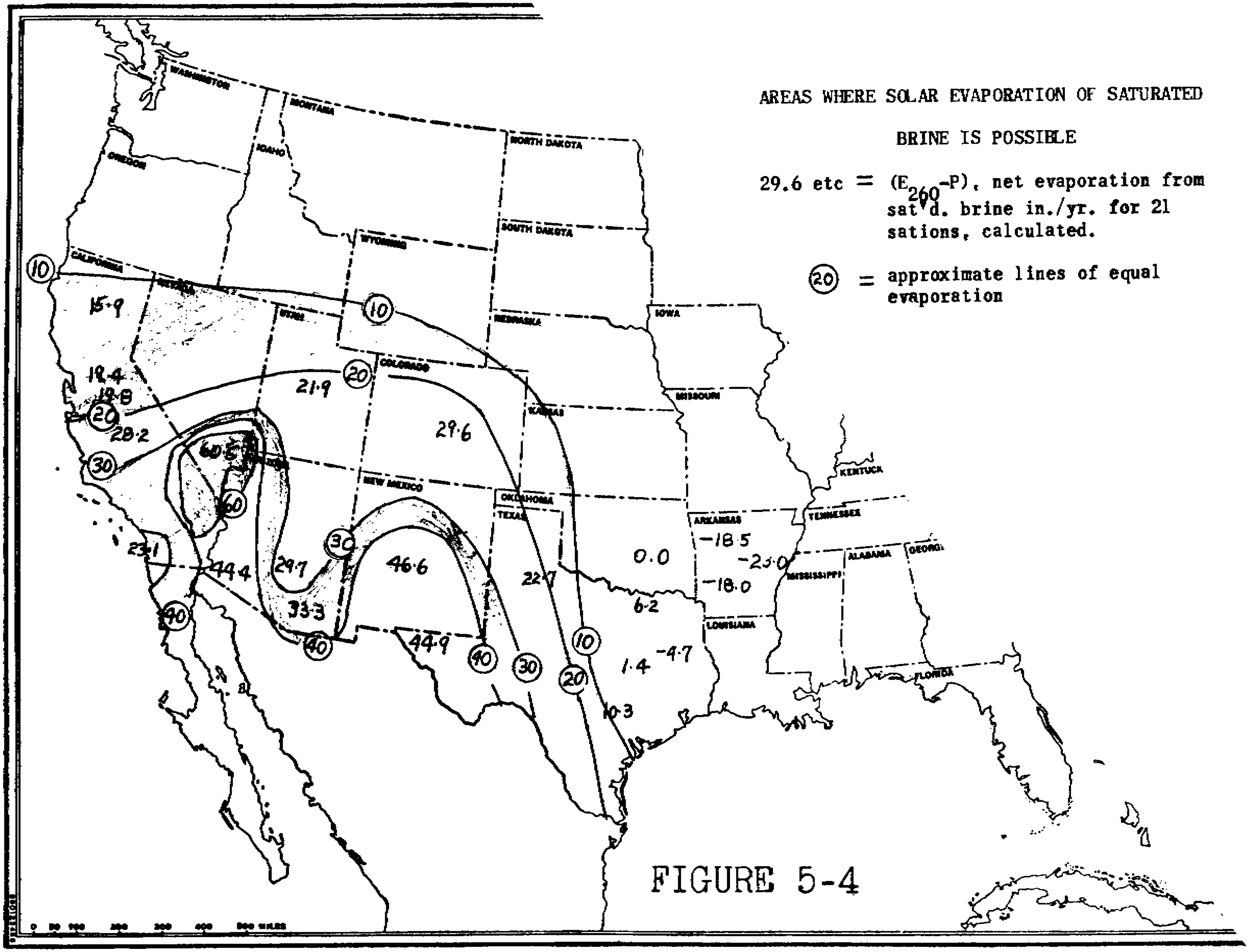
The data for net evaporation from saturated brine is shown geographically in Figure 5-4. The lines of equal evaporation shown are of course very rough. They should be refined and extended in subsequent studies. They are adequate however to show the region of appreciable evaporation from saturated brine is quite restricted.

Historically, and indeed at present, brine has been evaporated to crystallization in regions which are in the lower evaporation areas on this Figure, for example San Francisco, and even in regions which are far outside the "possible" area, namely at Syracuse, New York. The explanation is that both of these installations are concerned with the production of salt rather than the evaporation of water and reduction of volume thereby. At San Francisco (5-1) (5-6) evaporation occurs only during the summer months and harvesting of the crystal crop is done before the onset of the winter rains. The winter rains do not influence the operation because the rain that falls into vats is run off into the bay before the salt water is let in again in the next season. This, of course is not possible for our purposes where the pond must be in use 12 months of the year and must collect all the rain that falls on it. At Syracuse the evaporating vats were not only taken out of operation during the winter time but were even covered over with wooden covers during every rain storm (5-23). Neither of these devices, of course, can be utilized for our purposes.

Maximizing Evaporation Rate

However, it is possible to utilize some operating procedures which will maximize the overall evaporation rate of the waste brine. It has been demonstrated (5-3) and patented (5-24) (5-25) that the addition of certain dyes to solar evaporating vats can result in a practical increase in evaporation rate. Under the meteorological conditions in Israel the addition of 0.57 pounds of 2-napthol green per Mg of brine resulted in an evaporation increase of almost 20 per cent. The dye did not precipitate with the crystalline product. An empirical equation for the curves in Figure 5-2 has an exponent of about 1.0. This means that a 20 per cent increase in evaporation would result in a 20 per cent decrease in cost of evaporation. Thus at low values of evaporation rate around 10 inches the cost would be reduced by \$0.02/Mg while at high values of evaporation at cost of around \$0.01 it would be reduced by \$0.002. If the vat were being used as a crystallizing vat the mother liquor remaining could be pumped out before the crystals were harvested and thus there would be only a small use of dye. If the vat were being used for concentrating prior to injection or pipelining then of course the dye remaining in the mother liquor would be lost. In this case the dye would have to sell for less than 50 cents per pound in order to just break even, even at the low evaporation rates. While at first glance the situation looks uneconomic for our purposes it might be worth some further study.

In those cases where it is necessary to evaporate a dilute brine operational procedures may maximize the evaporation rate. For example, if a dilute brine is simply dumped into a vat which already contains concentrated



AREAS WHERE SOLAR EVAPORATION OF SATURATED BRINE IS POSSIBLE
29.6 etc = (E_{260}-P), net evaporation from sat'd. brine in./yr. for 21 sations, calculated.
(20) = approximate lines of equal evaporation
WASHINGTON
MONTANA
NORTH DAKOTA
OREGON
IDAHO
SOUTH DAKOTA
WYOMING
CALIFORNIA
NEVADA
UTAH
IOWA
NEBRASKA
COLORADO
KANSAS
MISSOURI
KENTUCK
NEW MEXICO
OKLAHOMA
TEXAS
ARKANSAS
TENNESSEE
MISSISSIPPI
ALABAMA
GEORGI
LOUISIANA
FLORIDA
10
15.9
19.4
19.8
20
28.2
30
60.5
60
23.1
44.4
40
29.7
33.3
21.9
29.6
46.6
44.9
22.7
0.0
6.2
-18.5
-23.0
-18.0
1.4
-4.7
10.3
0 50 100 200 300 400 500 MILES

FIGURE 5-4

brine or solid salt and if mixing is allowed to take place, then the entire volume of brine will become concentrated or even saturated and will suffer the low evaporation rate of concentrated brine. However, as much water must be evaporated to go from 6 to 12% as to go from 12% to saturation and therefore it is advantageous to keep the brine segregated so that at least half of the water may be removed at the high rate characteristic of 6-12% brine. This might be accomplished by cascading the separate vats thus bringing about segregation of the brine according to concentration. The same effect might possibly be accomplished by careful introduction of the dilute brine into the evaporating vat containing solid salts or nearly saturated brine. If this is carefully done it may be possible to stratify the brine so that the fresh brine remains on the surface and evaporates at its own characteristic high rate. Both of these possibilities should be studied further from both the technical and economic standpoint. In the present study, it is only possible to assume saturated brine evaporation rates for high concentration waste brines and for the evaporation to dryness process. For the process of concentrating to saturation rates characteristic of 150,000 ppm brine which are about half way between saturation and pure water should be taken. The area in which evaporation is possible for the 150,000 ppm brines is of course somewhat greater than that represented on Figure 5-4.

Brine Evaporation Correlation

To facilitate geographical comparisons an attempt was made to correlate net evaporation, brine with net evaporation, water and since the correlation is new and unexpectedly good it is presented in Figure 5-5.

Attention is directed to the lowest line on that Figure which correlates net evaporation for saturated brine with net evaporation for water. Despite the range in E_0-P from -15 to +80 and despite the variation in precipitation occurring over the wide geographic area from Arkansas to California, these points fall on a remarkably good line. The equation of that line is:

$$(E_{260}-P) = (E_0 - P) - 0.235E_0$$

When P approaches 0 or when E_0 is large with respect to P then

$$(E_{260}-P) \longrightarrow 0.765\ (E_0-P)$$

Not only mathematically but also physically it happens that when E_0 is large P is quite small -- in other words, regions of very high evaporation generally have very low rainfall. Thus, at large values of E_0 the curve merges into

$$(E_{260}-P) = 0.765\ (E_0-P)$$

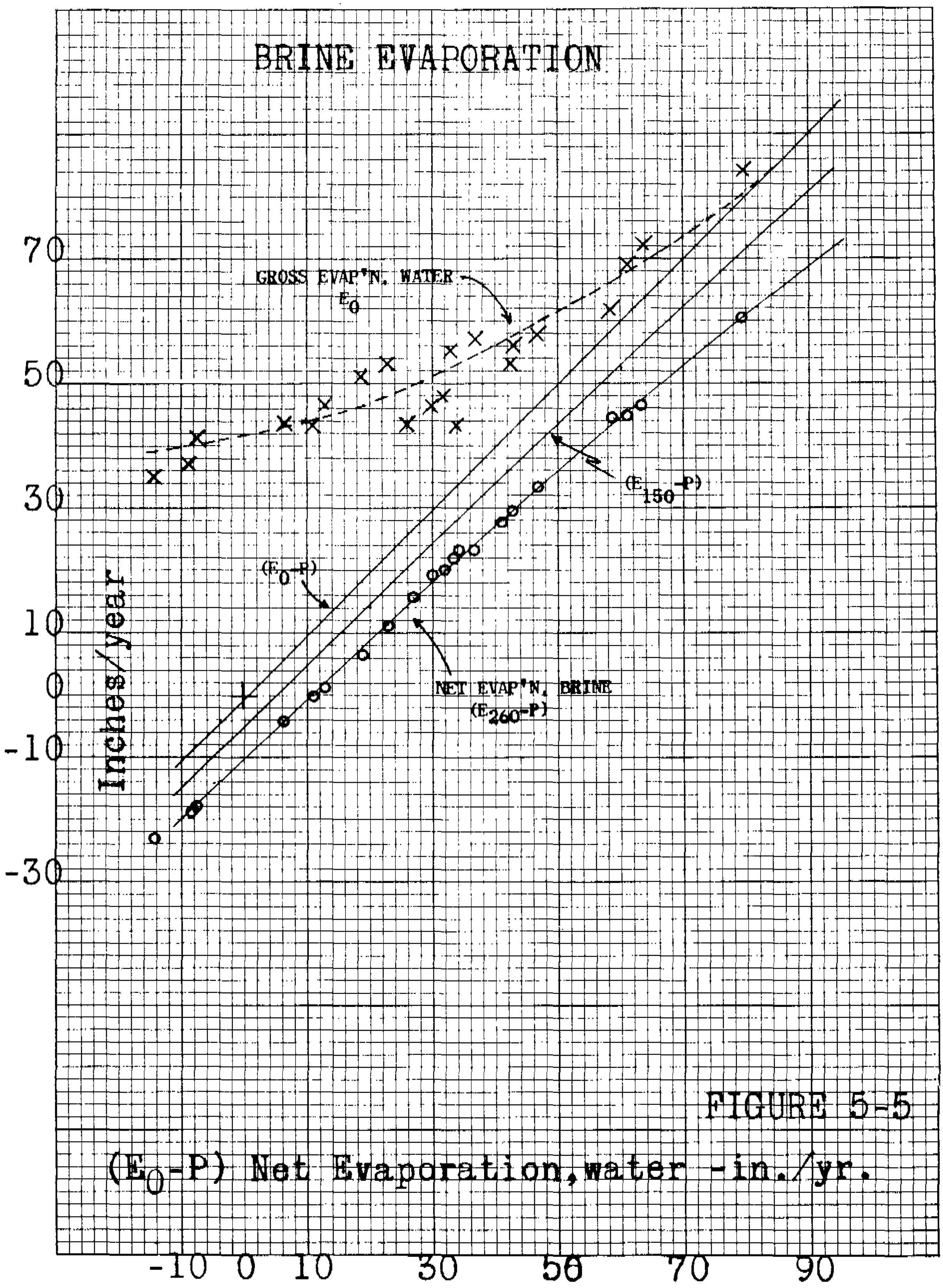

BRINE EVAPORATION
GROSS EVAP'N. WATER
E_0
$(E_{150}-P)$
(E_0-P)
NET EVAP'N. BRINE
$(E_{260}-P)$
Inches/year
70
50
30
10
0
-10
-30
-10
0
10
30
50
70
90
(E_0-P) Net Evaporation, water -in./yr.

FIGURE 5-5

At lower values of E_0-P the curve begins to deviate from this straight line. When $(E_0-P) = 0$ then:

$$(E_{260}-P) = -0.235E_0 = -0.235P.$$

The intercept on $(E_0-P)= 0$, and thus the general direction of the curve, depends on the actual magnitudes of E_0 and P at that point.

The uppermost curve in Figure 5-5 shows that E_0 is also a somewhat regular function of (E_0-P) which crosses $E_0-P = 0$ at about 41.

$$41 \times (-0.235) = -10.0$$

which is the observed intercept of $(E_{260}-P)$.

Figure 5-5 allows a determination, with some confidence, of net brine evaporation directly from net water evaporation. It shows that where net evaporation, water is less than 10 inches, saturated brine cannot be solar concentrated at all.

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CHAPTER 6

OPERATION: INJECTION

Synopsis - CURRENT PRACTICE - INVESTMENT COST OF INJECTION WELLS: Contract Cost of Drilling - Cost of Casing and Tubing, Economic Pipe Size, Cementing, Acidizing, Injectivity Profile, Electric Logging, Total Cost of Injection Wells - OPERATING COST OF INJECTION: Experienced Operating Costs, Power Requirements, Observed Casing Head Pressures, Other Experienced Operating Costs- THE CAPACITY OF UNDERGROUND STORAGE - REFERENCES

Synopsis After a review of current practice in waste injection, the investment cost of injection wells is developed. The operating cost under selected conditions is determined as well as capacity of underground storage.

CURRENT PRACTICE

Injection of oil field fluids underground for disposal and repressuring and sometimes for disposal alone is common practice at present. Less common is the practice of injecting industrial wastes. There are a large number of papers and a large number of installations on the former subject, a few papers and very few installations on the latter.

In oil field practice the largest operation and the most advanced technically through long years of experience is that of the East Texas Salt Water Disposal Company of whose operation a detailed study was made for this report. Over one and one-half billion barrels of salt water have been injected in the 95,000 acre field over the past 10 years, following extensive experiments beginning as early as 1931. While at first casing and tubing sometimes specially treated for corrosion resistance was used, the current practice is to use 7" bare casing and cement all the way to the surface from the 3700' depth of the formation. Corrosion is most severe at 400-600 feet but on the outside rather than on the inside of the casing. This is due to a gypsum water which occurs at that level. (6-1) (6-2) (6-3) (6-4)

An earlier system consisted of using both casing and tubing. The tubing was new, corrosion proof and carefully jointed, sometimescement lined. Packers (to contain the pressure at the bottom of the tubing) were not used because of corrosion and hazard. Instead, the pressure of the injection fluid was counterbalanced by oil in the annulus between tubing and the casing. (6-5) There is a large literature on case histories of injection and water flooding projects, unfortunately for the most part not detailed and comprehensive enough for use in the present study. Average wells take 100 Mgd and a number of the larger wells take 420-550 Mgd. Depths vary from 1500 feet to 11,500 feet.

A few chemical plants are starting to dispose of liquid wastes underground. The Upjohn Company at Kalamazoo disposes of 100 Mgd of wastes to formation at about 1500' through two wells. (6-6) The injection pressure is about 900 psi. The wells comprise 7" OD casing cemented, and bearing 2½" tubing. (6-6) (6-7) Parke Davis & Co. at Holland, Michigan operated from 1952-1954 and presumably to the present an injection well to 1400 feet comprising a 7" casing and a 2" tubing which can be replaced if it corrodes. (6-8)

It is said that the city of Houma, Louisiana is disposing of sewage to an 800 foot salt water aquifer. (6-9).

Other disposal wells have been used (6-10) at the McCarthy Chemical Co., Winnie, Texas, (now defunct), Magnolia Petroleum Co., Fremont, Texas, and a chemical plant in Oklahoma.

INVESTMENT COST OF INJECTION WELLS

Rule of thumb figures for the cost of injection wells have been obtained as follows:

Contract Cost of Drilling References (6-11) and (6-12) report a survey of 1956 of contract prices for oil well drilling in several parts of the United States. Prices are shown for footage and for day work, together with the number of days on day work for most of the wells. Footage prices are the prices per foot of hole drilled. In addition it is customary to charge for such on-the-job time as is not devoted to drilling - for example set-up time, setting casing, and the like. The latter varies from job to job depending on a number of circumstances. Of the data in the references 65 wells contain complete information on depth , footage rate, day work rate and days on day work. The footage prices themselves appear to be a linear function of well depth. Day work cost as a per cent of footage cost varies greatly and shows no trend. About three quarters of the cases show day work costs between three and sixteen per cent of footage cost. 60% of the cases lie between 4 and 14%. It was decided however that the variation was too great to be used in calculating. Figure 6-1 therefore shows the footage-plus-day-work prices for all 65 wells. The spread is naturally greater than for footage prices alone. The best line for our purposes is conveniently taken as

$$U = 0.85W$$

where

U = unit price (footage plus day work), \$/foot

W = depth of well, 1,000 feet

80% of the data lie within \$1.50/foot of this line.

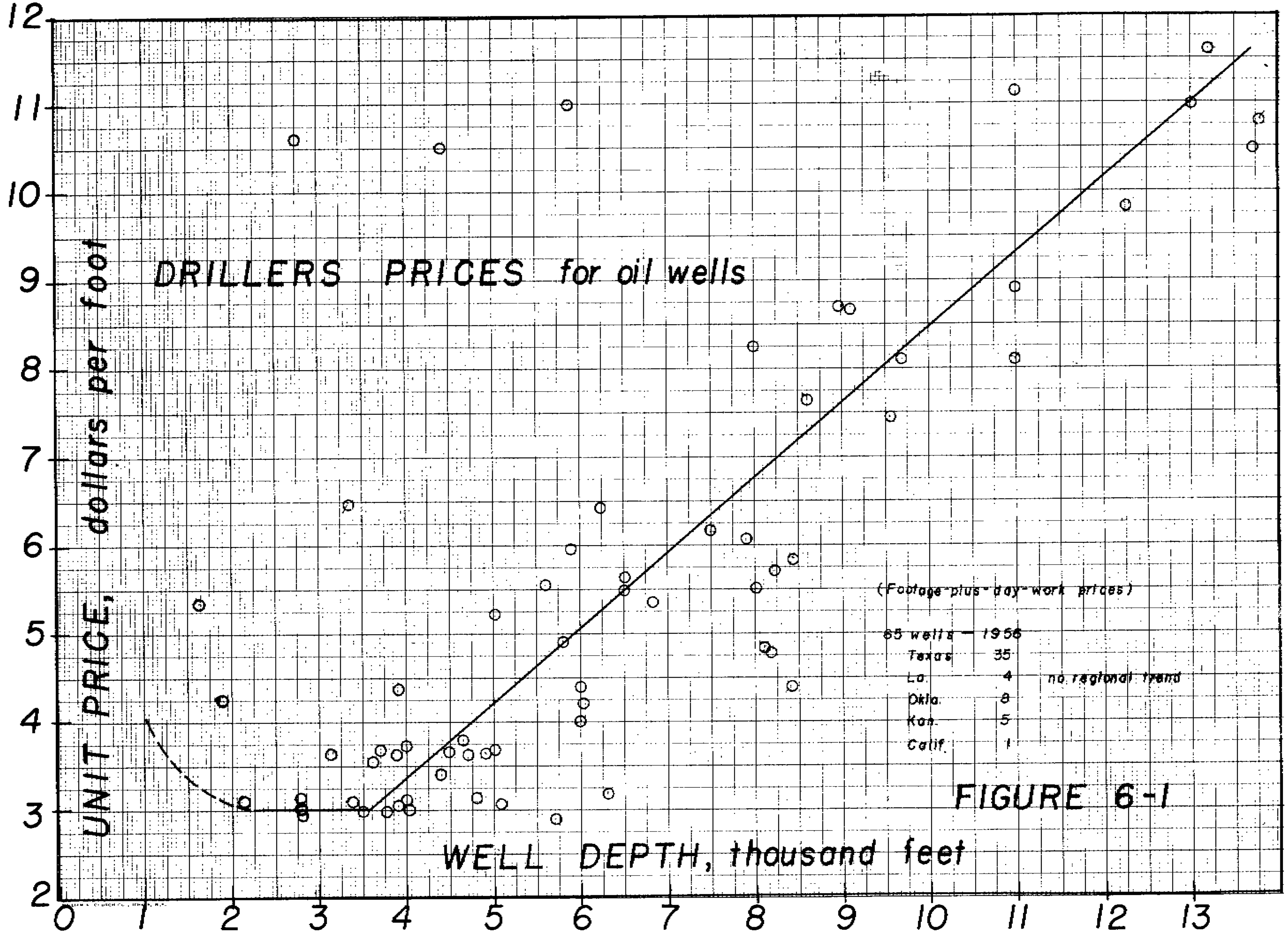

DRILLERS PRICES for oil wells
UNIT PRICE, dollars per foot
WELL DEPTH, thousand feet
(Footage-plus-day-work prices)
65 wells — 1956
Texas 35
La. 4
Okla. 8
Kan. 5
Calif. 1
no regional trend
2
3
4
5
6
7
8
9
10
11
12
0
1
2
3
4
5
6
7
8
9
10
11
12
13

FIGURE 6-1

$3.00 per foot seems to be a minimum price and there is indication that the per foot cost increases below 3,000 feet. An estimate has been used for these shallow depths as shown by the dashed line.

Cost of Casing & Tubing

Since literature data were not found on tubing and casing prices, inquiries were made. (6-12) (6-13) The prices obtained are shown in Figure 6-2 as price per foot per inch of inside diameter. As salt water injection wells must be well constructed to avoid leakage, new casing and tubing have been chosen for our calculations.

As indicated previously, some injection wells are operated with tubing, but the currently developed practice of the East Texas Salt Water Disposal Company comprises using a bare casing as a conduit and cementing all the way to the surface. Calculations were first made for wells using tubing and casing without cementing. Revised calculations used here for bare casing with cementing come out just slightly lower than the earlier calculations.

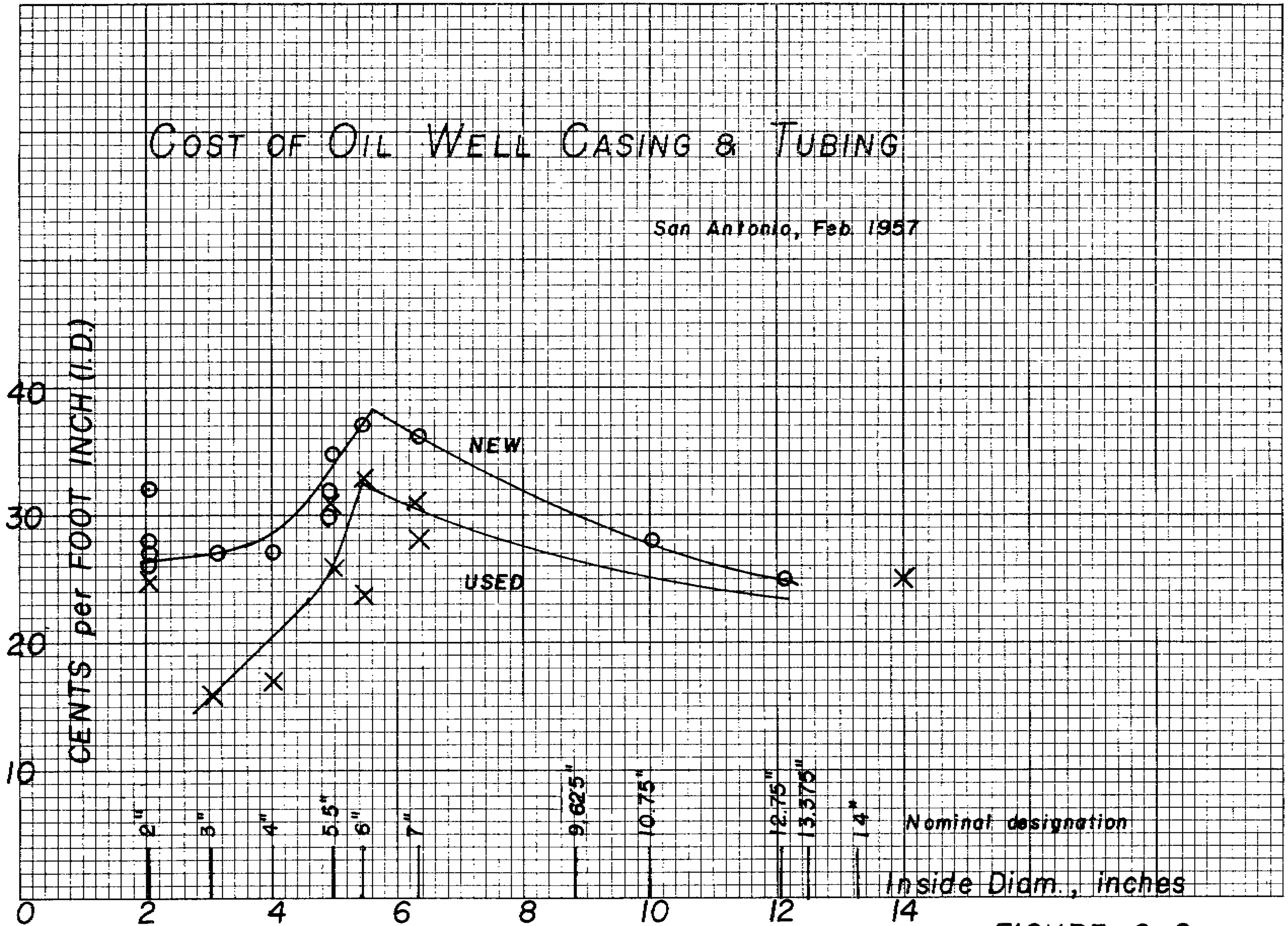
Economic Pipe Size

While the calculation of economic pipe size for an actual case could become fairly complicated depending on the exact hydraulics of the well, for our purposes they are taken from a standard economic pipe diameter nomograph (4-13) as follows:

Mgd	20	200	1,000	2,000
Economic ID inches	1.5	3.7	7	11
Nominal tubing or casing size, inches	2	4	7	13 5/8
Approximate velocity ft./sec.	1.3	3.5	--	4.0
Approximate friction head loss, ft./1,000 ft.	5	17	--	6

The head loss shown for the 200 Mgd seems out of line. Five inch pipe would give a head loss of five feet. However 4 inches is standard size and so will be used. Two inch tubing for the 20 Mgd would be used if tubing were to be used. However, when bare casing is to be used it is doubtful that casing below four inches in size would be set. Accordingly, in the calculations here presented the four inch size is used for 20 Mgd as well as 200 Mgd.

It is customary in drilling practice to use two or even three different sizes of casing in reaching completion depth, and this has been taken into account in the present calculations. For example, the 1,000 Mgd well at 10,000' depth is composed of 400' of 10 3/4" surface casing, 3100' of 9 5/8" and the lowest 6500' of 7". The 200 Mgd well at 4,000' is composed of 400' of 10 3/4" surface casing and 3600' of 4". The 2,000 Mgd well is composed of a straight run of 13 3/8" casing which is not conventional practice in oil well construction.



COST OF OIL WELL CASING & TUBING
San Antonio, Feb 1957
CENTS per FOOT INCH (I.D.)
NEW
USED
2"
3"
4"
5.5"
6"
7"
9.625"
10.75"
12.75"
13.375"
14"
Nominal designation
Inside Diam., inches
0
2
4
6
8
10
12
14
10
20
30
40

FIGURE 6-2

Cementing Cementing costs are composed of a charge for the cement, plus a charge for the cementing operation. (6-14) The per sack cement costs are as follows:

Cement	$ .81	(6-15)
Handling Charge	.35	(6-16)
Hauling Charge ($0.10/ton mile)	.47	
TOTAL	$1.63/sack	

The hauling charge was arrived at in the following way. One of the major cementing companies has 58 stations in 11 southwestern states, an average area of 21,500 square miles per station. If the stations were uniformly distributed each would be in the center of a square 147 miles on a side, 208 miles diagonal. While the stations are actually not evenly distributed, in compensation the other cementing companies presumably have stations which cover some of the intermediate territory. Accordingly, an average haul of 100 miles is assumed. A sack of cement weighs 94 pounds.

The charge for the cementing operation is based on the number of pumping trucks used. (6-14) A single truck can pump a certain number of sacks per hour. When the amount of cement required is large, it may require more than one truck to get it in within the allowable setting time. This is especially true in deep wells where high temperatures and thus short setting times are encountered. However, for our purposes a single truck is assumed.

The charges have been calculated into per foot costs as follows:

Depth Mf	1	2	3	4	6	8	10	12
$/foot	.23	.15	.10	.08	.06	.05	.05	.06

Reference (6-17) gives the figures for the number of sacks of cement per linear foot for various combinations of casing and hole. These figures have been used in the present calculation which are too detailed for presentation here.

Acidizing Acidizing is a process of forcing acid into the formation to open up larger pores and thus to increase the production or injectivity. About 90% of the producing oil wells have been acidized and about 20% have been fractured. (6-18) Several hundred water wells have been acidized. (6-19) Increases in production or injectivity of 150% and more are to be expected although a small percentage of cases show very little response. Since high injectivity is very much desired it is here assumed that all injection wells will be acidized on completion (as well as at intervals thereafter).

Acidizing costs are based on the following applicable in the Gulf Coast. (6-19)

Pump truck	\$210.00 (increases only nominally with depth)
Mud acid (for nonlimestone formations)	.51/gallon, minimum 500 gals.
HCl (for limestone formations)	.19/gallon
Acid per foot of perforation or open hole	100 gallons

The number of feet of perforation or open hole is subject to wide variations from formation to formation and from field to field. Reference (6-20) gives the average net productive thickness by region of oil bearing formation in a large number of fields in the Southwest. The range of the average for a given region and formation runs from 7' to 158' and the average of 83 such categories is 23.8 feet.

As a reasonable estimate for our purposes, we may take the average productive depth, 25 feet, and a more favorable case of twice that amount of 50 feet. Acidizing costs, which are practically independent of well depth then would range as follows:

	25 feet	50 feet
Nonlimestone formations	\$1270	\$2750
Limestone formation	685	1160

As an over-all average we may arbitrarily take \$1500 per well for the cost of acidizing.

Injectivity Profile It is probably desirable to run an injectivity profile of the well to determine the areas which will take water. This will cost about \$500. (6-21)

Electric Logging The well should be logged at least with the standard self-potential and three resistivity logs, the cost of these calculated as a function of depth is as follows. (6-22)

Depth Mf.	1	2	3	4	6	8	10	12
\$/foot	.29	.17	.14	.13	.12	.11	.11	.10

Total Cost of Injection Wells

The cost of injection wells here calculated is thus made up of the following components:

Independent of depth and capability
Acidizing, injectivity profile

Dependent on depth only
Cementing service, electric logging

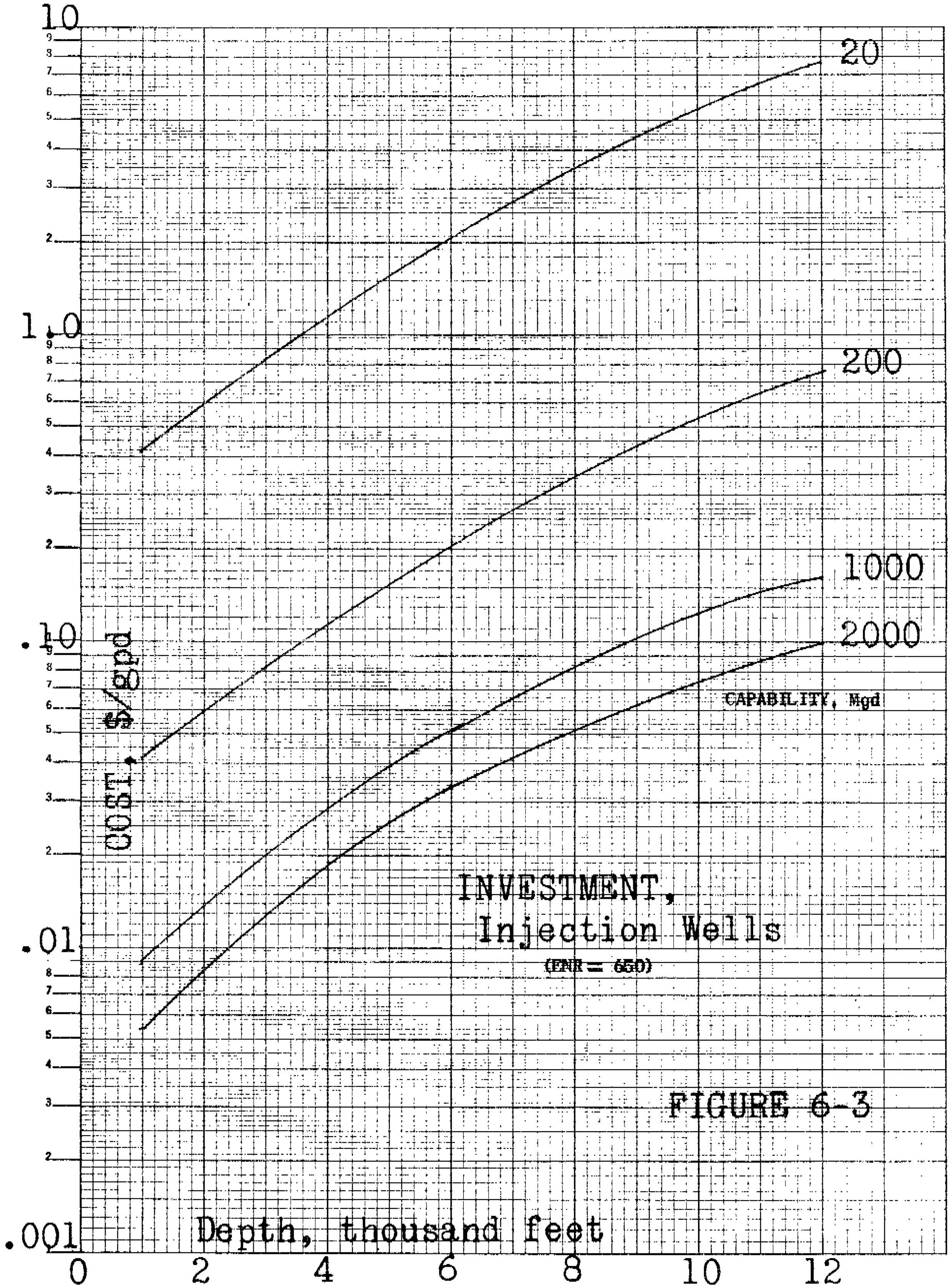
Dependent on depth and capability
Cement, drilling, casing

In choosing the per foot drilling cost in Figure 6-1, the higher level of the range shown has been used for the 2,000 Mgd well because 13 3/8" casing to the full depth of the well is a condition probably not included in the data from which the Figure was drawn. The 20 Mgd well is considered to have the same total cost as the 200 Mgd well since it is unlikely that casing smaller than 4" would be used no matter how small the flow. The sum total of all the above is shown in Table 6-1 and plotted in Figure 6-3.

TABLE 6-1

COST OF INJECTION WELLS

Q	2000 Mgd		1000 Mgd		200 Mgd		20 Mgd	
Mft	$/ft.	$/gpd	$/ft.	$/gpd	$/ft.	$/gpd	$/ft.	$/gpd
1	10.94	.0055	9.34	.009	8.61	.043	8.61	.43
2	8.74	.0087	7.00	.014	5.97	.060	5.97	.60
3	9.33	.0140	7.04	.021	5.48	.082	5.48	.82
4	9.87	.0197	7.32	.029	5.47	.109	5.47	1.09
6	11.42	.0344	8.99	.054	7.06	.212	7.06	2.12
8	13.08	.0523	10.43	.083	8.75	.350	8.75	3.50
10	14.78	.0740	12.27	.123	10.70	.535	10.70	5.35
12	16.50	.0992	13.58	.163	12.58	.756	12.58	7.56



10
1.0
.10
.01
.001
0
2
4
6
8
10
12
COST, $/gpd
Depth, thousand feet
20
200
1000
2000
CAPABILITY, Mgd
INVESTMENT,
Injection Wells
(ENR = 650)

FIGURE 6-3

OPERATING COST OF INJECTION

Experienced Operating Costs

Experienced operating costs of the chemical injection wells are not available because they are usually operated as a part of the utility function and they do not have a long enough record of operation to develop depreciation costs. Considerable cost data is available for oil field injection either for salt water disposal or for repressuring. For example, some California plants (6-23) show costs ranging from 0.25-2.0¢/bbl., equivalent to approximately $.06-.48/Mg. This is for single well plants including the treatment costs and gathering costs. The East Texas Salt Water Disposal Company (6-24) operating about 60 wells shows 1956 costs of 1.33¢/bbl. equivalent to about $.32/Mg but this also included treatment costs and extensive gathering lines. The "plant and well" expense alone for 1956 was $.137/Mg. This included the treatment cost but did not include general and administrative expenses

Figures such as these give a general idea of what is to be expected but do not serve our purposes because the extraneous costs cannot be withdrawn. Therefore, it will be necessary to calculate operating costs.

Power Requirements

An important part of operating costs will be the cost of energy and pumping equipment. This bears a highly complicated relationship to the number of well parameters as discussed in the following.

The steady state flow through the face of a well is given by

$$Q = \frac{.1289\ kh\Delta P}{\mu \lg\ r_e/r_w}$$

where

Q = Mgd injected
k = horizontal permeability, darcys
h = face height, feet
ΔP = driving pressure drop, psi
μ = viscosity, centipoises, for our brine taken as 1.0
r_e = edge radius (distance to edge of cylinder of injected material)
r_w = well radius, same units as r_e

The driving pressure drop is given by

$$\Delta P = P_{ch} + (.4331\ gD) - \Delta H - P_r$$

where

P_{ch} = casing head pressure, psi
g = specific gravity of fluid
D = well depth, feet
ΔH = friction loss, psi
P_r = reservoir pressure (pressure into well under static conditions equivalent to pressure at r_e), psi

The specific gravity of 2% and 26% NaCl is 1.02 and 1.20 respectively. We will use an average of 1.11.

ΔH will vary with the different sized tubing and casing used in the well. The tubing needed to carry the flow gives friction losses of 6-26 feet/ 1,000 feet over the various capabilities taken. However, except for the 2,000 Mgd capability, all the specified wells are made up with some tubing larger than the required size. For example, all these wells have 400 feet of 10 3/4" surface casing even though the pipe size needed is only 4 or 7 inches. Rather than making the extremely calculated computations for every capability and depth we will take an average $\Delta H = 12$ feet/1,000 feet. The driving pressure equation then becomes

$$\Delta P = P_{ch} + .4728\ D - P_r$$

Substituting in the previous equation for ΔP gives

$$P_{ch} = \frac{Q\ \lg r_e/r_w}{.1289\ kh} + P_r - .4728\ D$$

Horsepower required is

$$HP = \frac{\text{Mgd} \times P_{ch}}{2468.6}$$

The ranges of parameters encountered in normal underground practice are such as to lead to tremendous variations in P_{ch}. The extremes of the ranges normally encountered as well as the midpoints of these are shown in the following Table.

TABLE 6-2

NORMAL RANGES OF WELL PARAMETERS (6-25)

	For Max. P_{ch}	For Min. P_{ch}	Midpoint	Actual East Texas Field
r_e	2000	500	1250	- - -
r_w (this study)	.167	.5	.333	.53
k	.020	3.0	1.51	2.0
h	5	200	102.5	51
P_r	4000	150	2075	1021
D	2000	12,000	7000	3625
Q				420

When the values for maximum P_{ch} are used they yield prohibitively high casing head pressures, over 9,000 psi even for the 20 Mgd case. When the values for minimum P_{ch} are used they yield negative pressures (i.e. the well head would be under vacuum) up to capabilities well in excess of any that would ever be used (141,000 Mgd). When the midpoint values are used the casing head pressure is negative (i.e. no pumping would be required) up to 6860 Mgd. Using the midpoint conditions but varying r_w in accordance with the actual casing sizes corresponding to each capability, the depths deeper than which no pumping is required vary from 4400' at 20 Mgd to 5120' at 2,000 Mgd.

All of the above indicates that it is impossible to make general predictions of casing head pressure.

Calculating for actual East Texas conditions gives results which are in accord with the facts and incidentally shows that the calculated casing head pressures are not very sensitive to the value usually arbitrarily taken for r_e:

r_e, ft.	1000	2000	10,000
P_{ch}, psi	-585	-575	-553

The actual casing head pressures in the East Texas injection practice are gravity to 350 psi. Also illustrated by this are two other factors of variability, namely well-to-well variability and day-to-day variability. Thirty of the 59 currently operating East Texas Salt Water Disposal Company injection wells are operating without pumping, taking an average of 420 Mgd/well. There is no trend to the pressure requirement. One well may take the injection water by gravity while another only a few thousand yards away may require pumping to pressure of 350 psi. Also a well may operate for several weeks or months under gravity flow and then rather suddenly require pumping. One reason for some of this variation is the unpredictability of the formation face. In one case a well supposed to be penetrating 80-90 feet of productive oil sands was surveyed by the "spinner" method which gives the injectivity profile. It was found that only two feet out of the total face thickness was actually taking water.

Observed Casing Head Pressures

Because of the failure of the above theoretical approach to yield useable pressure data an attempt will be made to develop this on a more empirical basis. Reference (6-25) lists 124 Texas fields having water injection operations, and shows the casing head pressure for each. A statistical analysis of these 124 fields shows an average casing head pressure of 260 psi which is also the median pressure. 23 per cent of the fields are under gravity flow while 90 per cent have casing head pressures less than 900 psi. On this basis we will develop horsepower and horsepower costs for three different casing head pressures - 0, 260 and 900 psi. A more complete study would no doubt warrant investigation of casing head pressures throughout the United States.

Other Experienced Operating Costs

The following compilation shows experienced operating costs (ENR = 650) for injection in East Texas and California.

	East Texas 10 Mb/d 60 wells $/yr. well or pump (6-24)	Calif. 3 Mb/d 1 well $/yr. well & pump (6-23)	Selected for this study
Repairs to gas engines and pumps	2610		see text
Cleanout & repair wells	675		700
Operating labor	1040	2070	1500
Maintenance labor	820	$\left.\right\}$ 1035	1000
Maintenance	- - -		

The East Texas data is taken from the "plant and well" account and an attempt has been made to separate out the plant costs. This has not been possible with the Claifornia data. The figure of $2610 for repairs to gas engines and pumps is about twice as much per horsepower as recommended for gas engine pipeline pump stations in Reference.(4-15) It seems better to neglect this experience figure anyway since we will estimate on electric pumps rather than gas. Reference (4-15) suggests $1.00/horsepower year for pump and electric motor repairs which we will increase to $2.00 because the pumps are rather small and possibly mobile. Power cost is taken from Reference (4-15) as used in Chapter 4 on pipeline costs. The fixed charges on pumps should probably be based on 20 years rather than 40 years. The East Texas Salt Water Disposal Company uses a depreciation corresponding to approximately 23 years on a straightline basis. Reference (4-12) shows the yearly cost of this on the decreasing balance basis to be 7.4 per cent. Taxes and insurance bring this to 9.4% resulting in:

$$.258 \times \$/\text{gpd} = \$/\text{Mg}$$

Summarizing, the operating costs are computed as follows:

TABLE 6-3

OPERATING COSTS OF INJECTION

On Capital	$/Mg		
Pumps, motors	.258 x $/gpd		
Wells	.178 x $/gpd		
On Days	$/day		
Repairs to wells	1.92		
Operating and maintenace	6.85	if no power	3.42
Total	8.77		5.34
On Horsepower	$/HPd		
Repairs to motors, pumps	.0055		
Power	.192		
Total	.1975		

The total cost of injection is shown in Table 6-4 and plotted in Figure 6-4.

TABLE 6-4

COST OF INJECTION, $/Mg

Depth	20 Mgd			200 Mgd			2,000 Mgd		
M ft.	0 psi	260	900	0 psi	260	900	0 psi	260	900
1	.342	.562	.647	.0342	.0821	.150	.00364	.0331	.100
2	.373	.592	.678	.0373	.0851	.153	.00421	.0337	.101
3	.412	.632	.717	.0412	.0890	.157	.00522	.0347	.102
4	.460	.680	.765	.0460	.0938	.162	.00617	.0357	.103
6	.644	.864	.949	.0644	.1122	.181	.00880	.0383	.105
8	.890	1.110	1.195	.0890	.137	.205	.0120	.0415	.108
10	1.220	1.440	1.525	.1220	.170	.238	.0158	.0453	.112
12	1.628	1.848	1.933	.163	.211	.279	.0203	.0498	.117

The cost of injection at 1000 Mgd is interpolated as about 50% greater than at 2000 Mgd. This information is of importance, if it should prove impossible to have an injection well of 2000 Mgd capability, in which case two 1000 Mgd would be needed. These themselves would be almost twice as large as the largest current injection wells (about 550 Mgd).

THE CAPACITY OF UNDERGROUND STORAGE

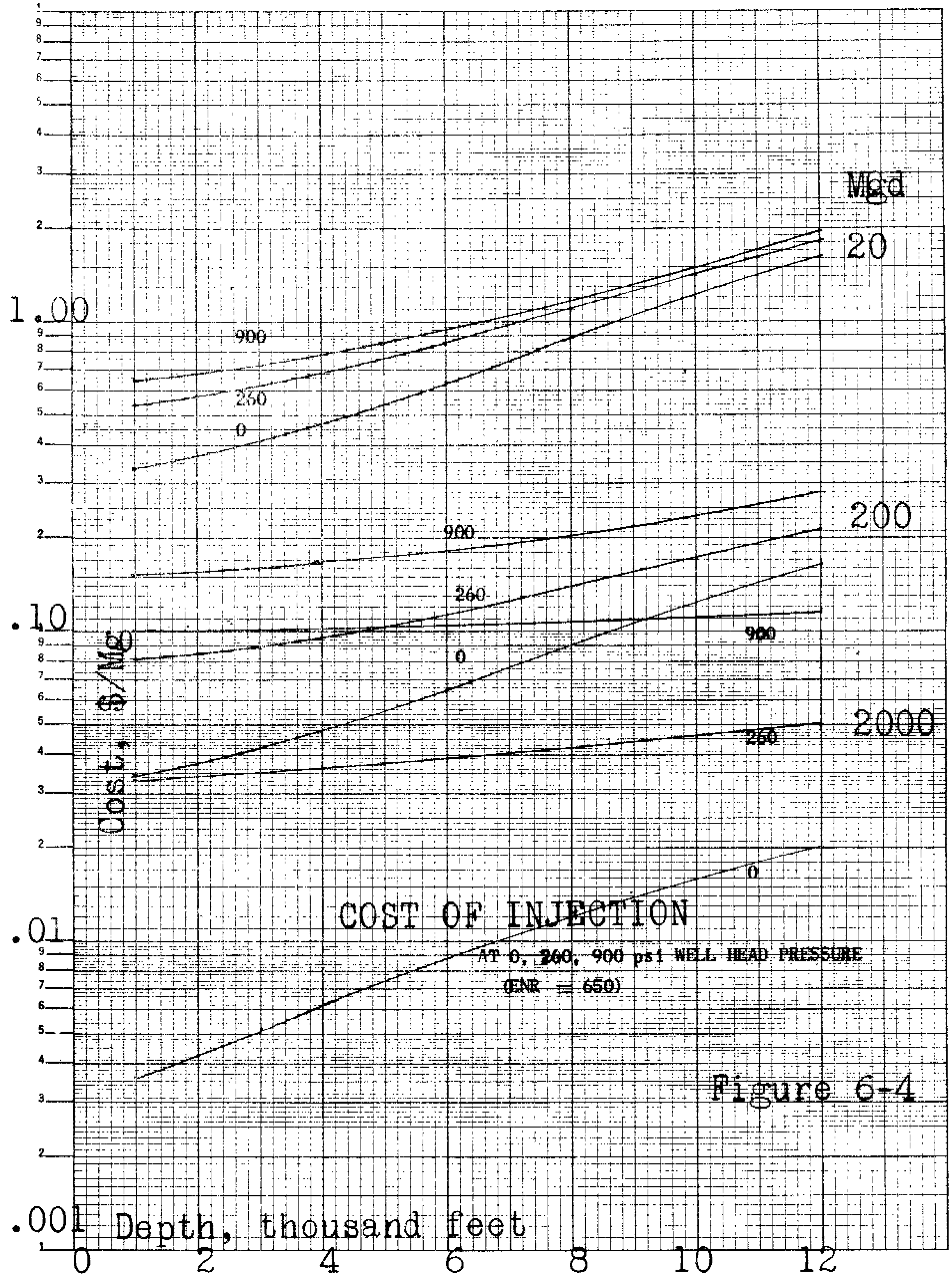
Measured by everyday standards the volume of storage space available underground is enormous. Assuming that the injected fluid moves out from the well in a cylinder and fills the available porosity, the radius reached at any time will be

$$r_e = .0236 \times \left(\frac{Q}{h} \times \frac{y}{p}\right)^{1/2}$$

where

r_e = radius to which injection fluid will reach
y = years
p = porosity cu. ft./cu. ft.
h = height of formation, assumed constant with distance, ft.
Q = Mgd

Under typical reservoir conditions with porosity about 25% when Q/h equals 1, that is with 20 feet of face and 20 Mgd capability then in 100 years the front of the injected liquid will have traveled only about one-half mile and in 2500



Mgd
20
200
2000
1.00
.10
.01
.001
900
260
0
Cost, $/Mg
Depth, thousand feet
0
2
4
6
8
10
12
COST OF INJECTION
AT 0, 260, 900 psi WELL HEAD PRESSURE
(ENR = 650)

Figure 6-4

years it will have traveled less than 2.5 miles. Under more extreme conditions in putting 2,000 Mgd into the same 20 foot face in 100 years it will have traveled 4.75 miles and in 2500 years 23 miles.

There is an important difference between salt water disposal in an operating oil field and salt water disposal from saline water conversion plants. This is that the salt water returned to an oil formation or pumped into it for pressurizing is filling in the pore spaces which are vacated by the original reservoir fluid. Typically one to five barrels of water would be removed from the producing wells with each barrel of oil and then the water but not the oil is returned to the formation. In the 5:1 ratio 5 barrels of water are being injected into the space from which 6 barrels have been removed. The mechanism of this is not difficult to visualize.

However, in disposal of saline water conversion brines the attempt will usually consist of trying to inject water into a formation when nothing is being removed from the formation. An exception to this occurs when the conversion plant is operating on brackish ground water and the waste is reinjected into the same formation in order to repressure the brackish water wells. In that exceptional case it is quite conceivable that repressuring of a confined brackish water reservoir or indeed repressuring of a confined fresh water reservoir might be possible with saline water conversion waste. If the reservoir is a renewable reservoir, however, and we are talking in terms of scores and hundred of years, brackish water should not be injected into it. Other than for this exception it is somewhat difficult to visualize just what is going to happen to the saline water conversion waste injected underground.

In the production of water from confined aquifers it is said that much of the water comes via the mechanism of compaction of the formation as the pressure is relieved. Surprisingly large quantities of water per acre are said to result from such compaction. If this is true the reverse might also be possible and the injection pressure might expand the formation enough to accomodate very large quantities of water. These subjects are not too well understood and can only be alluded to in the present study.

Suffice it to say that there are at present a number of operating installations which are returning water to a formation other than that from which it came, and from which no other withdrawals are being made (6-1). These installations have not been sought out in the present study.

The subject is of great importance because at present there is no way of predicting whether the injection pressure will build up as fluids continue to be injected and fill up the formation. If we were concerned only with pumping water into unoccupied spaces the day of reaching the reservoir boundary and suffering build-up of pressure or overflow would be as shown by the calculations above, far in the future. However, although the fluid front does not move fast the pressure front might move much faster. The subject needs thorough study by geologists and ground water hydrologists and reservoir engineers before injection can be considered a permanent method of ultimate disposal in the sense that dumping into the sea would be.

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CHAPTER 7

OPERATIONS: LAND DUMP, ABANDONING, SEA DISCHARGE

LAND DUMPING

With a view to providing a dumping ground closer to the plant site than the sea might be, an investigation is made of the factors involved in dumping liquid or solid wastes in isolated valleys or basins which are of no forseeable use in the future and which are hydraulically confined both surface and underground. In the intermountain region many such playas and dry lakes exist which now serve as the ultimate basins for the small local drainage. Some of these such as Owens Lake, and Searles Lake are exploited for their brines. While it is not possible in a study of this scope to pinpoint the location of such basins suitable for land dumping the accompanying map, Figure 7-1 suggests that so far as land value is concerned numerous such sites exist. This map shows the value of land and buildings per acre and gives a rough guide to the price which would have to be paid for purchase of land as an ultimate disposal site. Since there are large areas shown as below $25 per acre the average figure $20 per acre is used in the present calculations. A more thorough study would use the actual average value which might be as low as a few dollars an acre in the particular regions under study.

Of interest both for land dumping and for abandonment are the following relations:

$$h = 5.204 \times 10^{-8} C_2 E_t, \text{ feet/year}$$

$$T_s = .00152 \times C_2 Q_2, \text{ tons/year}$$

$$A_t = .13.44\ Q_2/E_t \text{ acres}$$

where

h = feet per year of accumulated dry salts at average bulk density of 100 lbs./cu.ft.

C_2 = concentration of waste dumped

E_t = net brine evaporation, in./year

Q_2 = capability, Mgd of waste dumped

T_s = tons solids deposited per year

A_t = acres required for evaporation surface

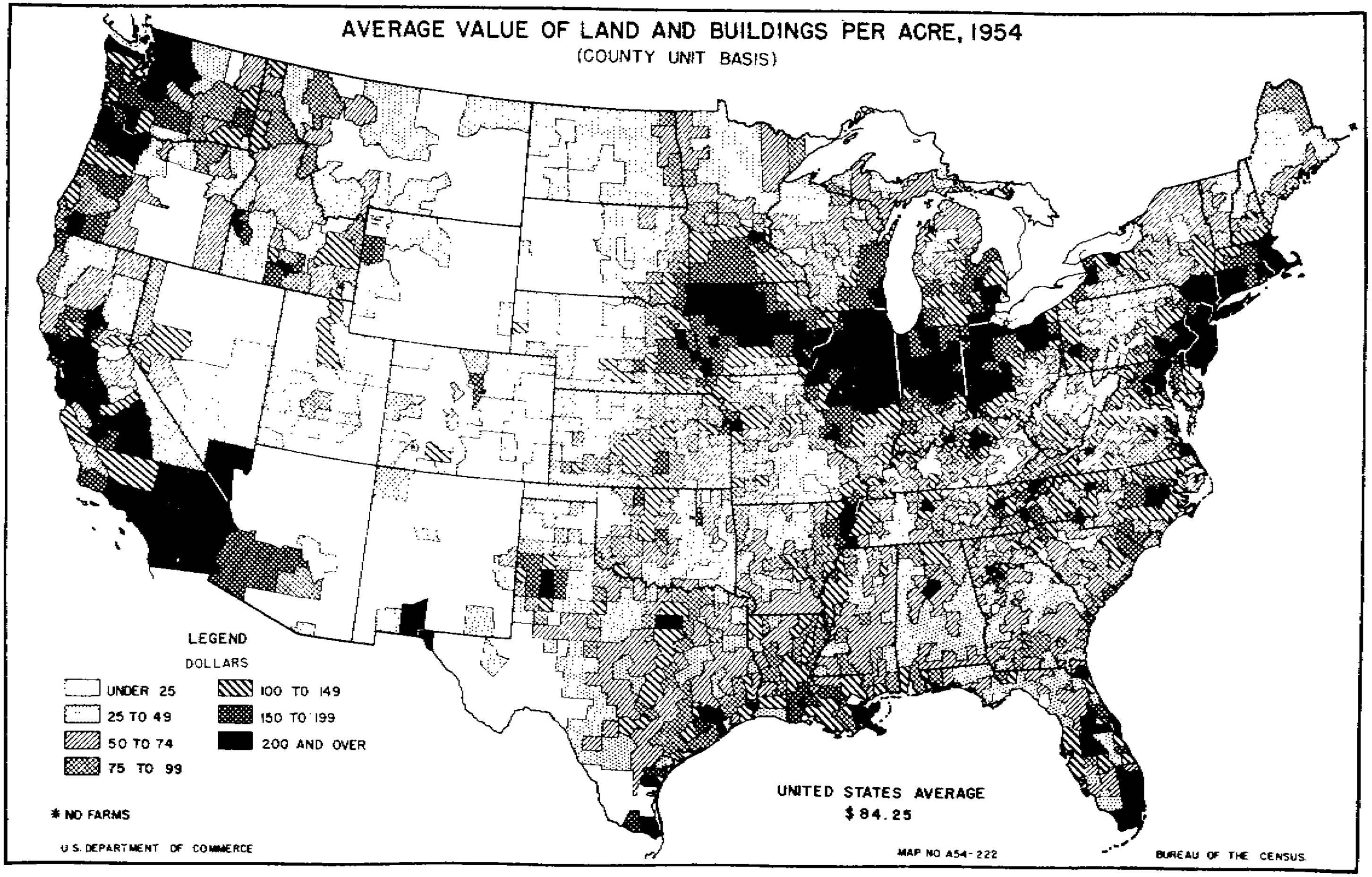

AVERAGE VALUE OF LAND AND BUILDINGS PER ACRE, 1954
(COUNTY UNIT BASIS)
LEGEND
DOLLARS
UNDER 25
25 TO 49
50 TO 74
75 TO 99
100 TO 149
150 TO 199
200 AND OVER
* NO FARMS
UNITED STATES AVERAGE
$ 84.25
U.S. DEPARTMENT OF COMMERCE
MAP NO A54-222
BUREAU OF THE CENSUS

FIGURE 7-1

Land Dumping Liquids It is assumed that both in land dumping of liquid waste and in abandonment the acreage required will be at least as great as that required to evaporate the entire waste annually. These figures have already been developed in Chapter 5. The following table shows the number of feet per year of salts that will build up in an evaporating basin or land dump operated under these conditions.

TABLE 7-1

BUILD-UP OF SOLIDS IN LAND DUMPS
Ft./year

Concentration ppm of waste dumped	2500	25,000	250,000
Evaporation, inches per year			
20	.00260	.0260	.260
40	.00520	.0520	.520
60	.00780	.0780	.780

Inspection shows that in a hundred years of operation a land dump or abandonment vessel will build up at the most 7.8 feet of salts at concentrations up to 25,000 ppm if it has an area just sufficient to handle the evaporation. However, operation with a saturated liquor will build up 26 to 78 feet of salts in a century depending upon the evaporation rate. While 8 or 10 feet per century might be considered reasonable for accumulation in land dumping, 80 feet per century may be arbitrarily judged excessive. If 10 feet per century is considered a reasonable limit then the concentrations allowable depend upon the evaporation rate as follows:

$$C_2 = 1922 \times 10^3/E_t$$

E_t in./yr	20	40	60
C_2 ppm	96,100	48,050	32,030

The following calculations are based on using an acreage equal to the evaporating acreage up to the limiting concentrations above; and beyond these acreages to give ten feet of salts per century, which are:

$$A_{10}/Q_2 = 10^{-3} \times .0070\ C_2, \text{ acres/Mg waste dumped}$$

For illustration the acreages necessary for a saturated solution, 260,000 ppm, are 36, 364, 3,640 respectively for 20, 200, and 2000 Mgd. The acreage required is shown in Figure 7-2.

Before a site can be chosen as a dump it would be necessary to have a very thorough geological and hydrological examination made of the terrain to establish that no possible seepage or surface flow could get out and become harmful to the area around the dump. This investigation will have to be more intensive than those used to study local seepage from evaporation ponds, etc.

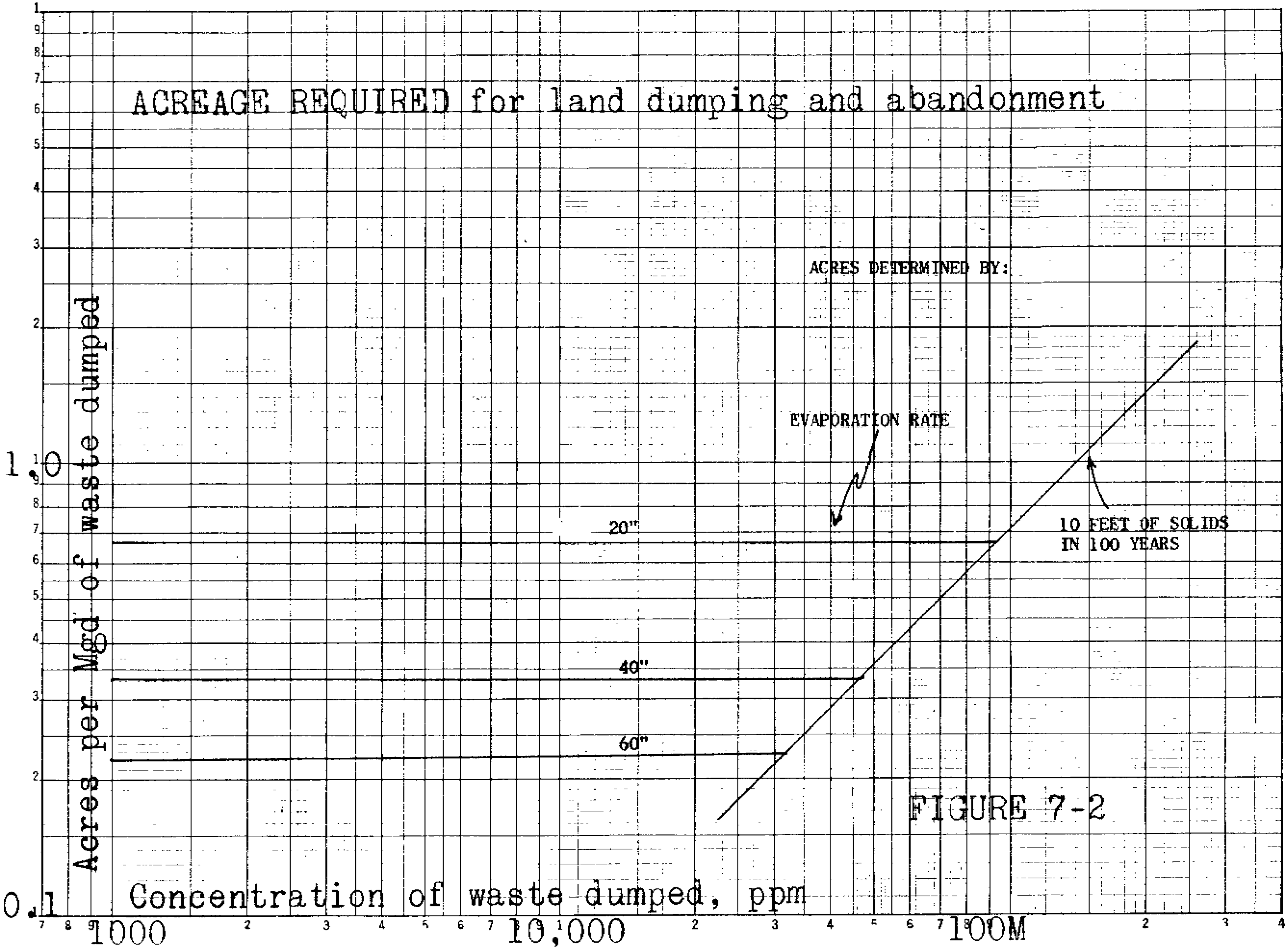

ACREAGE REQUIRED for land dumping and abandonment
ACRES DETERMINED BY:
EVAPORATION RATE
10 FEET OF SOLIDS IN 100 YEARS
20"
40"
60"
Acres per Mgd of waste dumped
Concentration of waste dumped, ppm
1.0
0.1
1000
10,000
100M

FIGURE 7-2

Both land dumping and abandonment contemplate use of the area over a period of centuries. The cost of this investigation is a part of the investment cost. It is taken as \$500 per acre in the range 5-15 acres covering the 20 Mgd case, \$100 per acre in the range 50-150 acres, (200Mgd), and \$20 per acre in the 500-1500 acres (2000 Mgd).

The investment cost then is taken as the sum of the land cost and the geological survey cost and is shown in Figure 7-3.

The diagonal line shows the cost of acreage to give ten feet of solid salts per century. This line naturally dips below the horizontal lines at various concentrations depending on the evaporation. The cost of land to give 10 feet per century would be less than the indicated cost based on the evaporation in the concentrations below these intersections. Acreages larger than the 10 feet per century figure are used in order to give enough evaporating surface to remove all the water if necessary, i. e. if seepage should be zero. The operating costs for land dumping are taken simply as the fixed charges on the investment at the 6.5 per cent per year figure previously established. This is not strictly correct for although the geological survey fee does constitute a part of the investment it presumably does not become part of the taxable value of the land. On the other hand, the insurance charges for such an operation contemplated over such a long term might be higher than 1 per cent of the total investment. A separate Figure for operating costs is not presented because the figures are obtainable by multiplying the investment costs shown in Figure 7-3 by the factor 0.178.

Land Dumping of Solids

When land dumping is used for disposal of dry solids, considerations of evaporating surface are no longer needed and the criterion of 10 feet per century of solids build-up may be utilized at all concentrations. This means that the acres required will be less than those required for saturated solutions at low concentrations. The acreage is:

$$A_{10} = 10^{-3} \times 0.0070\, C_1 Q_1$$

where

C_1 = concentration of original waste, ppm

Q_1 = Mgd of original waste

Some of the acreages thus calculated fall outside the ranges given previously for geological costs. Those acreages below 5 acres are calculated at a flat fee of \$2500; those in between the ranges are calculated at an average of the per acre charges for the two ranges. Land cost is taken at \$20 as before.

It is assumed that the operating expenses for land dumping of solids will be the same as for land dumping of saturated liquor. Actually the saturated liquor may require work on ditches, embankments and the like, not needed for dry solids, but, compensating, the dry solids will require shifting of railroad spurs, etc. These detailed estimates are not made in this study because the cost of land dumping turns out to be insignificant in all cases.

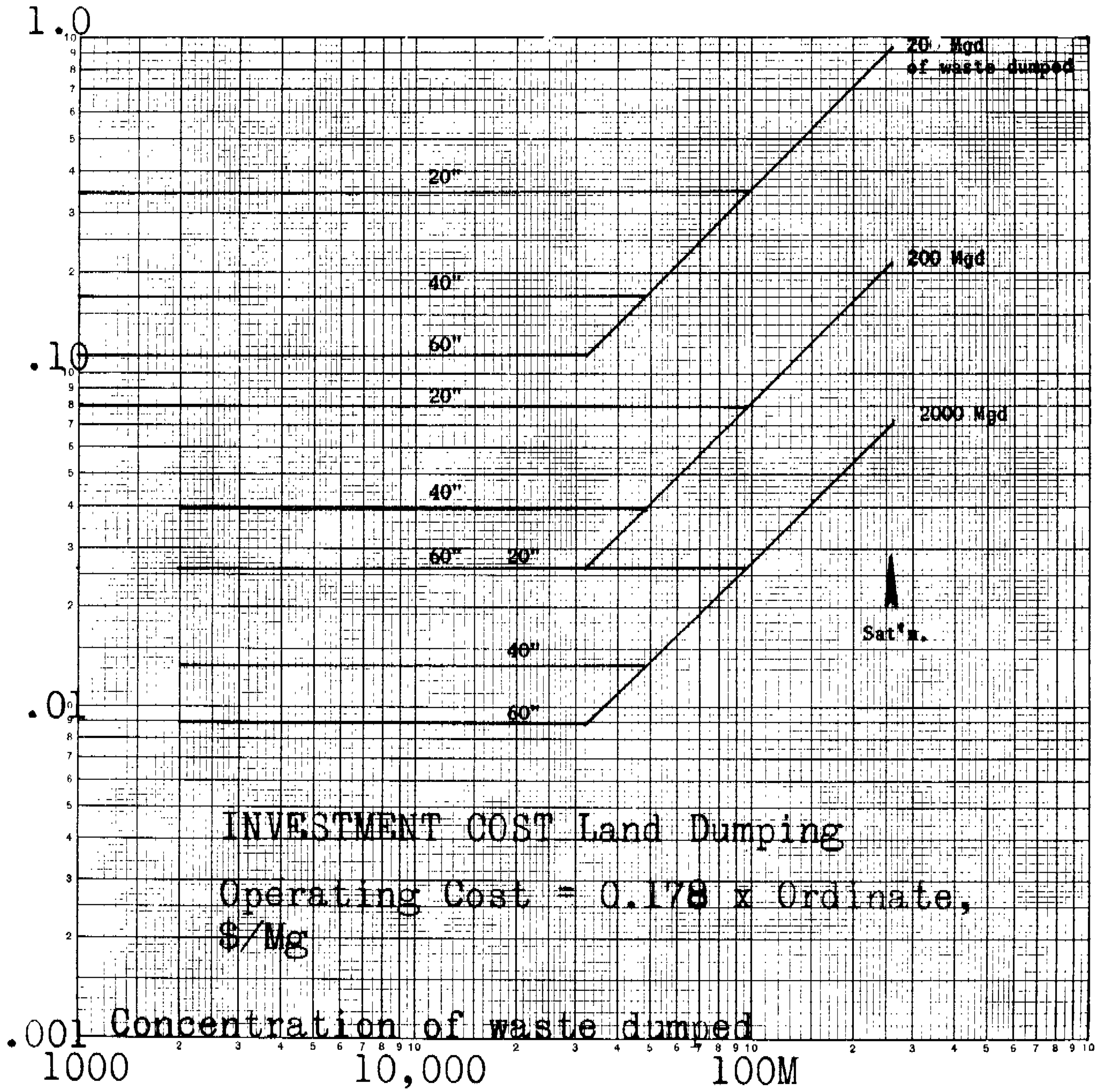

1.0
.10
.01
.001
1000
10,000
100M
20 Mgd
of waste dumped
200 Mgd
2000 Mgd
20"
40"
60"
Sat'n.
INVESTMENT COST Land Dumping
Operating Cost = 0.178 x Ordinate, $/Mg
Concentration of waste dumped

FIGURE 7-3

The investment costs calculated in the above manner are shown in Table 7-2. Also shown is the operating cost for the 2000 Mgd case which will be used for illustration later.

TABLE 7-2

INVESTMENT AND OPERATING COSTS
Land Dumping of Solids, 10 ft./century

Ppm in Orig. Waste	1000		10,000		100,000		260,000	
Mgd Orig Waste	\$/gpd	\$/Mg	\$/gpd	\$/Mg	\$/gpd	\$/Mg	\$/gpd	\$/Mg
20	.125		.126		.364		.41	
200	.0126		.0364		.0840		.145	
2000	.00364	.0006	.00840	.0015	.0280	.0050	.0636	.0103

ABANDONING

The ultimate in seeking proximity of the disposal area to the plant site is to have it at the plant site. The idea would be to locate the conversion plant at a moderate distance, say five or ten miles from the limits of the city so that the expense of conveying the product water to the city would be no more than that usually involved in transmission lines and therefore could be considered as part of the transmission cost rather than part of the conversinn cost. At the same time the plant site would be adjacent to large acreages of land which could be used as dumping grounds for scores of years with a view to ultimate abandonment of them and permanent containment of the waste. It is no doubt something of a horrifying thought to consider the destruction and abandonment of large acreages in the vicinity of water using centers. The more so since the material abandoned would constitute a pollution hazard in perpetuity and would have to be given perpetual care. It would undoubtedly require concrete construction. In these aspects the proposed solution is similar to that for the containment and permanent storage of radioactive waste. For complete sealing it might be proposed to pour a concrete slab over the entire vat after it had become full of salts. This would double the cost of the tank and presumably would only be resorted to in regions where rainfall might cause overflowing of the tanks and contents.

The cost of this operation is calculated for 2000 Mgd and 40 inches evaporation. Acreage required will conform to the curve in Figure 7-2 and is 672 acres up to a concentration of 48,000 ppm and a log-log straight line increace thence to 3640 acres at 260,000 ppm. The costs will be taken as for concrete lined evaporating tanks but considering the proximity to urban areas the land cost will be taken at \$600 per acre. This gives a total cost of about \$7,000 per acre, and an investment cost per gpd of capability of \$2.35 and \$12.70 respectively.

Since the tanks are designed to last in perpetuity it probably would be reasonable to take the depreciation period at greater than 40 years, say 100 years which reduces the fixed charges from 6½% to 5% and gives:

$$\$/\text{gpd} \times 0.137 = \$/\text{Mg}$$

The maintenance costs are taken as for evaporating vats, \$.107/acre day. The resulting costs are \$.359/Mg at concentrations up to 48,000 and an exponential rise from there to \$1.935/Mg at 260,000 ppm.

The above cost is composed of about 90% fixed charges and 10% maintenance costs. The costs therefore vary inversely as the evaporation up to the limiting concentration and from thence to saturation exponentially as the concentration.

SEA DISCHARGE

The sea, of course, even in the geological sense is the ultimate repository for all the wastes of the land and is the only completely safe disposal dump. The sea's capacity to absorb waste of the type under discussion may be taken as infinite so far as human activity is concerned.

In this study the Great Salt Lake is also considered a sea suitable for disposal of saline water conversion wastes. The Great Salt Lake has dimensions of about 80 x 30 miles or 1,535,000 acres. The evaporation from saturated brine there is computed from pan evaporation at about 37 inches per year. The total evaporation is 4,250 mgd. This evaporation in a 1:1 product-to-waste ratio, would supply 70 cities the size of San Antonio, Texas, and represents over four times the capacity of the Los Angeles aqueduct. The municipal and industrial use of water in the 17 western states in 1950 was 6,220 mgd (7-1) and the population in urban and associated areas was 21,623,000. The daily use in municipalities and industries was therefore 287 gallons per capita per day. At this rate Great Salt Lake evaporating capacity could take care of the needs of a population of 14,800,000.

However, unlike the dry desert lakes, Great Salt Lake now contains a body of water which is already evaporating at the above rate, the evaporated water coming presumably from some inflow into the lake. While a study has not been made it is believed that the Lake area is shrinking and therefore that the evaporating capacity of the present area of the lake is greater than the inflow. The evaporating capacity is equal to about 2,000 waste disposal plants of the largest size studied in this report, 2000 Mgd. Therefore, it is quite safe to say that a few or a few dozen plants of that size discharging into Great Salt Lake would hardly be noticed as they would increase the evaporating load only a few tenths of a per cent or a few per cent, respectively. Nevertheless, any contemplated large scale disposal into Great Salt Lake should be preceded by hydrological studies to determine the effect on the Lake level, contour and area. In addition such a study should cover the effects on the plans of chemical companies for utilization of Great Salt Lake brines.

The above considerations have covered some of the total effects of sea discharge on the receiving body. Also it is necessary to consider some of the local effects. It is assumed that the structures necessary for sea dumping will consist of a simple outfall line carrying the waste below the low tide line. Such a structure will require some engineering to avoid erosional effects which might undermine it, but for the purposes of the present study it is assumed that these structures will be but minor details of the extensive pipelines leading to them.

More important, is the possible local effect of waste discharge on shore installations and activities.

The conclusion is that there will be no cost associated with sea dumping.

REFERENCES

(7-1) MacKichan, Kenneth A.: Estimated Use of Water in the United States, U.S.G.S. Circular 115, May 1951. 13 pp.

CHAPTER 8

OPERATION: DISCHARGE TO FLOODING STREAMS

Finally, it is possible to discharge the wastes to streams. Discharge of industrial wastes to streams has been the simplest method of "disposal" for centuries. Within the past century attention has been given to "purifying" the waste before discharging to streams so that the pollution load does not exceed the self purifying capacity of the stream. This historic and modern practice of discharging to streams however is quite different from the problem of the present study for there are no possibilities for "purification", self or otherwise, of saline water conversion wastes. This practice has also been encountered previously and has given rise to the so-called "dilution method" of ultimate disposal. In this method wastes are discharged at such a rate that the resulting dilution in the flowing stream makes them unnoticeable or if noticeable does not bring their concentration to harmful levels. Reference (8-1) describes a modern installation of the dilution method where wastes from an industrial plant are dumped in the Great Miami River in a manner controlled by the flow and concentration of the river. Uncontrolled discharges of industrial wastes are made to a number of our major rivers. A recent study of one situation is found in Reference (8-2).

In the regions of the country where saline water conversion will be most useful however, the flow of the rivers is not large enough or steady enough to allow continuous discharge even if controlled. In the more arid regions of the country the rivers are at very low stages for long periods and most of the year's flow occurs in the flood season. Called for accordingly is the storage of wastes until times of flood flow and the controlled discharge at these times.

In this type of flow it is also quite common that the low flow waters are high in dissolved solids while the flood waters are dilute. This comes about through diverse causes, not the same for all rivers. In a typical case the salts picked up by the run-off and river flow are those which come within the reach of run-off by capillarity and other diffusional processes including the slow movement of underground water which may seep into the river bed. The normal salt content of the low flow stages represents the total amount of such material diffusing per day in the area wetted by the normal stream flow or run-off. In times of flood there is a great deal more flowing water but this does not alter the rate of the diffusional processes supplying the salt. Accordingly the flow is dilute compared to normal flow.

This is a simple explanation of a general situation to which there are many exceptions. For example, where there is no run-off during a long dry period the stream collects only the salts which diffuse to its bed. If now a general rainstorm occurs the first flood waters will pick up the salts collected on the dry portions of the drainage area. Thus, the first flood waters may be relatively high in salt. Another anomaly sometimes occurs when normal flows immediately after a flood period are found to be more dilute than normal. Various divergencies from ideal behavior as must occur with natural streams make it necessary to study each stream before planning a specific discharge program.

However, for our purposes it is desirable to demonstrate the feasibility of the method. To do so would require not only an extensive study of streams in the arid regions but also an intensive study of the detailed flow characteristics of each. This would be a major undertaking but we shall attempt to demonstrate the method of approach and the feasibility of the the operation by means of a single example. The example chosen is the Canadian River near Amarillo, Texas.

It is first necessary to demonstrate that the dissolved solids content does decrease as the flow increases. This is shown in the flow-salinity diagram of Figure 8-1. (8-3) (8-4) (8-5) (8-6) Not all of the points available in the references are plotted on the diagram because so many of them occur in the "normal flow" region that they become superfluous. While the points are rather scattered the envelope shows that a definite trend does exist.

It next becomes necessary to establish some reasonable concentration limit up to which the river may be "loaded" with waste. Much argument, legal and otherwise, could surround this question and undoubtedly will. For the present we will take a rational approach in assuming that at no time will the river concentration be raised above the concentration of "normal" flow. This means that any time any downstream user of the flowing, i.e. undammed, river might expect water of a quality which normally exists in the stream. "Normal" for the case chosen will be taken as that daily flow which is exceeded on only approximately 10 per cent of the days of the year. The downstream user of an undammed stream will thus suffer only the damage that during the 36 out of the 365 days of the year when he might expect dilute flood waters, he now will be receiving flood waters of the same concentration as he is accustomed to for the other 329 days of the year.

Reference (8-7) and (8-8) present data which show that the daily flow of the river was less than 100% of the average daily flow on 91.4% of the days in the water year 1951 and 1952 (October-September) and 89.2% of the days in 1952-1953. The weighted average concentration of the river water in these periods of less than 100% of average daily flow may be obtained by reading from Figure 8-1 the ppm corresponding to the flow, and taking the weighted average. In the present study this has been done by using certain ranges of percent-of-average-daily-flow and reading the ppm corresponding to the midpoint of the range. The weighted average concentration for this normal flow in 1951-1952 was 1170 ppm, in 1952-1953, 1160 ppm.

The total tons of salts actually carried by the river may now be calculated by summing:

$$\text{cfs} \times \text{ppm} \times \text{days} \times .00269 = \text{tons per year}$$

for each per-cent-of-average-daily-flow category using the midpoint flow, cfs, and the midpoint concentration, ppm, read from Figure 8-1.

This computation shows that 66.9 M tons was carried in 1951-52 and 66.7 in 1952-1953.

> These figures do not correspond with the weighted average tons per day given in References (8-4) and (8-5) which are 77.0 and 91.1 M tons respectively. The reason has not been explored but probably lies in the use of percentage categories and midpoint flows and concentrations in place of the more accurate day-to-day or even hour-to-hour summations presumably used in the reference. Also, the weighted average daily flows in References (8-4) and (8-5) do not correspond with those in References (8-7) and (8-8); reason unexplored.

When the same procedure is applied to the total flow of the river taking a constant concentration of 1170 ppm it is found that under these conditions the river could have carried 114 M tons in 1951-1952 and 145 M tons in 1952-1953. This

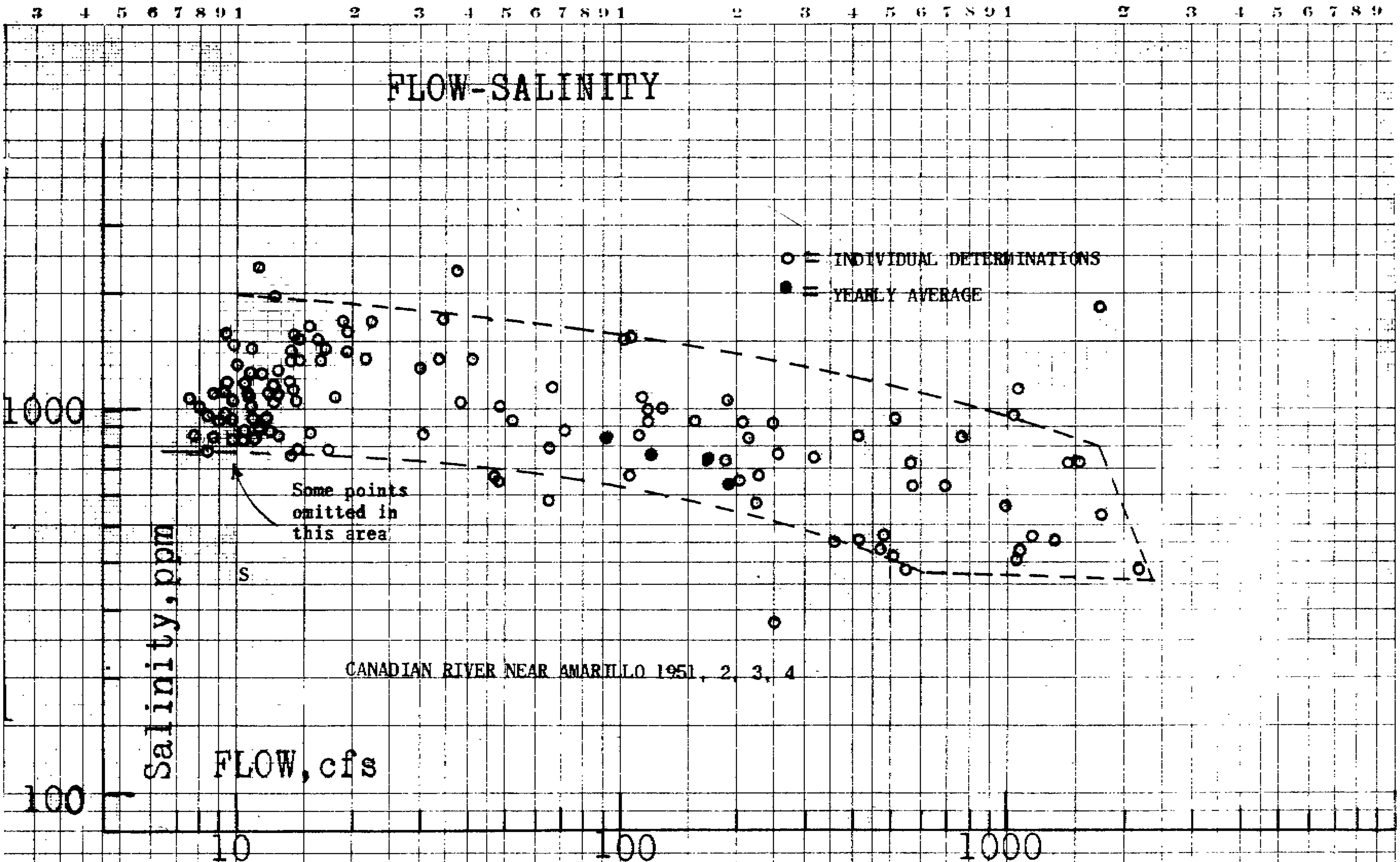

FLOW-SALINITY
o = INDIVIDUAL DETERMINATIONS
● = YEARLY AVERAGE
Some points omitted in this area
CANADIAN RIVER NEAR AMARILLO 1951, 2, 3, 4
Salinity, ppm
FLOW, cfs
1000
100
10
100
1000

FIGURE 8-1

means that the river could have absorbed 47,000 tons of waste salts in 1951-1952 and 78,000 tons in 1952-1953. Figure 8-2 shows the solids content of wastes at various concentrations and capabilities. Taking a typical brackish water waste as possibly 20,000 ppm it is seen that the river could easily have accomodated a 200 Mgd plant in both years. In 1952-53 it could have taken all the waste from a 2,000 Mgd plant and could almost have done so in 1951-1952.

The Canadian River was chosen because of the availability of quality and flow data, and also because it does not have a nearby upstream dam controlling the flow at Amarillo. (It does have 7000 square miles of its 19,000 square mile drainage area controlled by Conchas Dam in New Mexico, 200 miles away. And the extreme low flows at Amarillo are maintained by the city sewage effluent.) Short of carrying out similar studies, presumably in a more refined form for numerous other rivers it is not possible to say whether the Canadian River at Amarillo is typical. It may happen that the Canadian River at Amarillo is the only river in the entire Southwest capable of assimilating 50,000 tons per year of salts. On the other hand it may be that it is rather limited compared to the other rivers in this regard. The only firm conclusion that can be drawn from the illustrative example is that at least one river in those two years (in which the flow was 1/3 the 15 year average) had the capability of absorbing the waste from a fairly large saline water conversion plant without at any time causing the concentration to rise above "normal".

However, this is not done without cost for as is to be expected, flood flows do not occur uniformly throughout the year but are concentrated in flood season. In 1951-1952 there were some low flood flows in April and May but the higher flood flows which account for the major tonnage of assimilable salts occurred between July 17 and August 30. In 1952-1953 these larger floods occurred between July 19 and August 22 and no floods above 100% of the average daily flow occurred outside of the period July 19-September 3. This means that in general almost a full year's storage of waste must be provided for. The exact amount of storage (as the exact amount of evaporating area in Chapter 5) can only be determined by a day-to-day analysis of dischargeable wastes depending on the river stages and this of course must be done on a statistical basis. For our present purposes it seems reasonable that a one year's storage be assumed.

The investment cost of such storage may be obtained from the data in Table 5-2 on the cost of evaporating tanks. The storage cost is that of evaporating tanks at 60 inches evaporation (corresponding to the five foot depth of tank). This would be, for a five foot tank, $1.45/gpd for concrete and $.95/gpd for soil-cement. However, it is likely that a storage tank would not be limited to a five foot depth and might be constructed for approximately the same costs per acre in a 15 foot depth. (The cost of soil-cement and concrete tanks is largely the cost of lining). The investment cost of storage tanks would therefore be about one-third of the above.

Similarly the operating costs may be determined from Figure 5-2 which at an evaporation of 60 inches in soil-cement is $.14/Mg, practically independent of capability. All of the contributing costs are proportional to the acreage and therefore the operating costs of a 15 foot storage tank would be one-third of the cost of the evaporating tank or $.047/Mg. It is presumed that the storage tanks would discharge to the river by gravity flow. In a detailed study some attention should be given to the cost of the supervision, river monitoring and control necessary for this disposal operation.

SOLIDS CONTENT OF WASTE

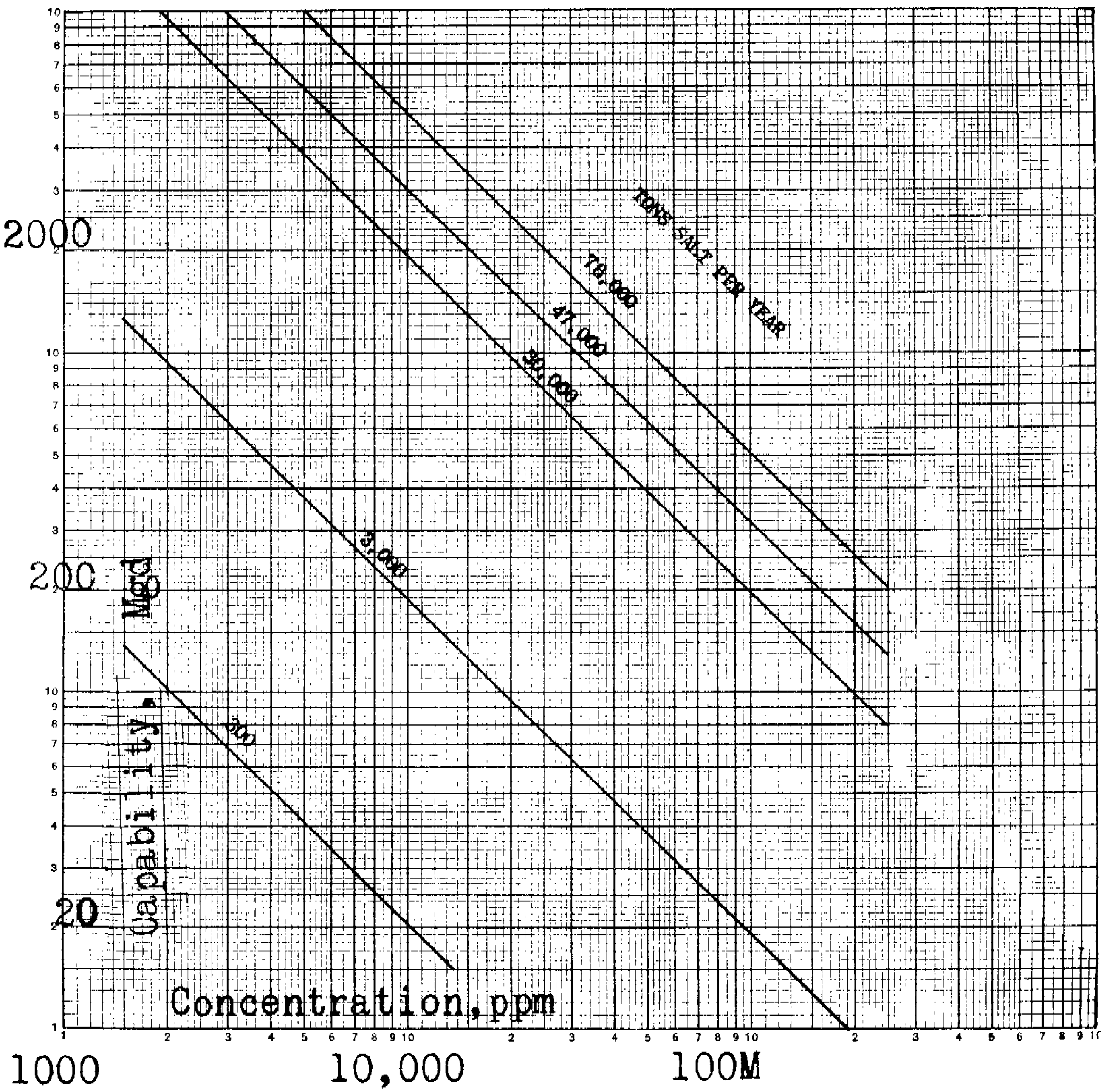


FIGURE 8-2

REFERENCES

(8-1) Kline, Hubert S. and Fletcher, Joseph F.: The Dilution Method for Industrial Waste Disposal. General Motors Engineering Journal, September-October 1954, p 38-43.

(8-2) Brine Contamination in the Muskingum River, Ohio River Valley Sanitation Commission, 1951, 26 pp.

(8-3) Chemical Composition of Texas Surface Waters, 1951. Texas Board of Water Engineers. ca 50 p.

(8-4) Same, 1952.

(8-5) Same, 1953.

(8-6) Same, 1954.

(8-7) Surface Water Supply of the United States, 1952, Part 7, Lower Mississippi Basin. U. S. G. S., Water Supply Paper 1241, 1955.

(8-8) Same, 1953. Water Supply Paper 1281, 1956.

CHAPTER 9

PROCESS I: CONVEY TO THE SEA

The simplest of the disposal processes contemplated comprises conveying the waste material to the sea, or to the Great Salt Lake, which as discussed in Chapter 7 constitutes for our purposes a sea. Figure 9-1 shows the area of the western United States in relation to its distance from the nearest seacoast. A total of 150,000 square miles in the 17 western states lies within 500 miles of the sea or Lake. Only about 15% of this is in the 0-100 mile range. The distribution as indicated on the map is approximately as follows:

TABLE 9-1

DISTRIBUTION OF LAND BY DISTANCE FROM THE SEA

Miles		Square Miles	Per Cent
0-100		22,000	15
100-300		75,000	50
300-500		53,000	35
	Total	150,000	100

Only a small proportion of the land could enjoy a conveyance distance of less than 100 miles.

However, this doesn't matter particularly since conveyance costs for even a 100 mile distance are prohibitive. This is shown in the following table.

TABLE 9-2

CONVEYANCE TO THE SEA

Mgd	\$/Mg mi.	\$/gpd mi.	Op. Cost \$/Mg 50	100	300	500	Investment \$/gpd 100	300	500
20	.040	.263	2.00	4.00	12.0	20.0	26.3	79	131
200	.0182	.0500	.91	1.82	3.64	9.10	5.00	15.0	25.0
1000	.0088	.0213	.44	.88	2.64	4.40	2.13	6.39	10.65
2000	.0064	.0153	.32	.64	1.92	3.20	1.53	4.59	7.65
100,000	.0011	.0033	.055	.11	.33	.55	.33	.99	1.65

The 50 mile column is inserted for use in a later chapter.

With the best conversion processes showing costs of 30-50¢/Mg and the most expensive ones being considered at \$2.00/Mg it would appear that none of the nine original combinations 20, 200 and 2000 Mgd and 100, 300, and 500 miles

DISTANCES FROM THE SEA

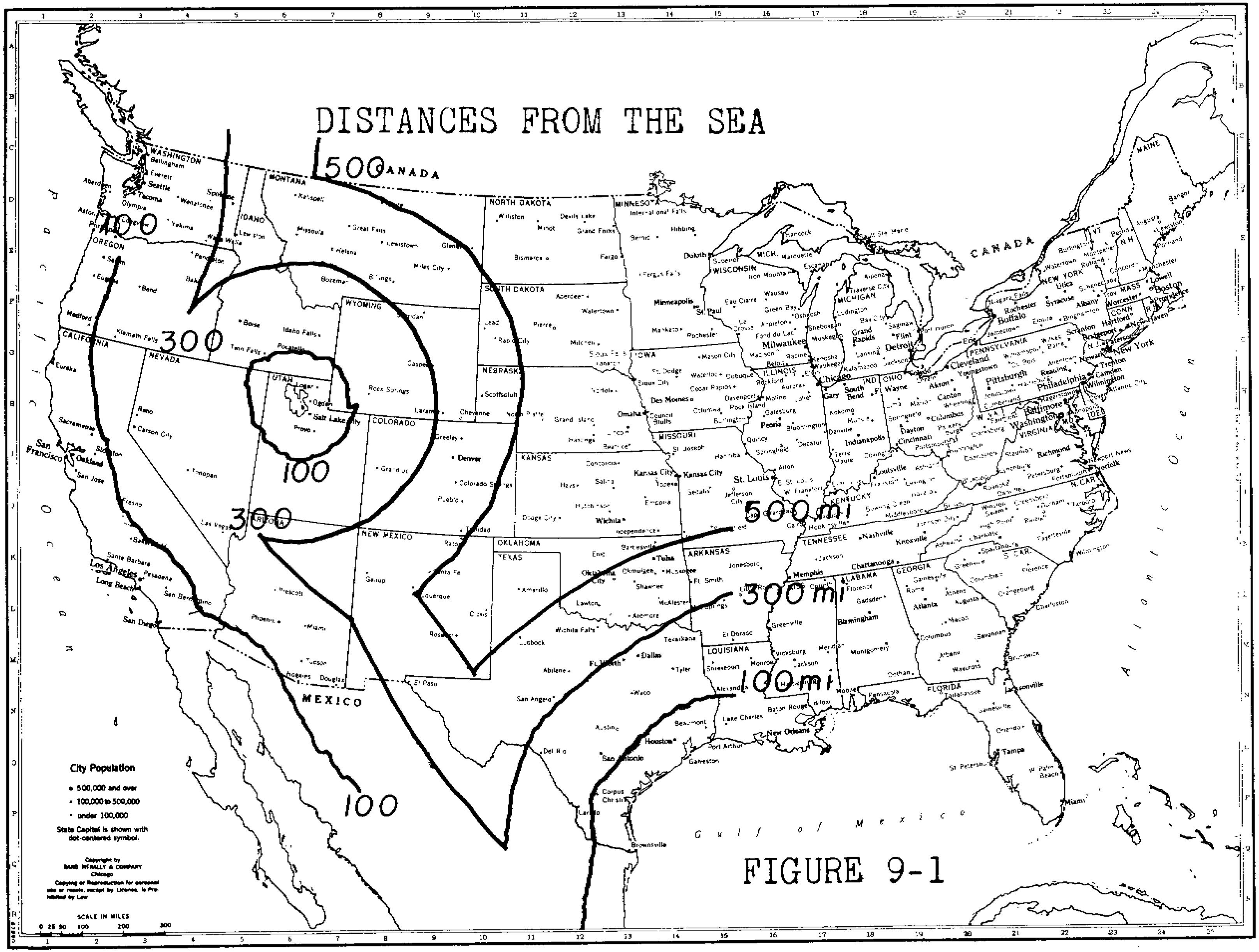


FIGURE 9-1

would allow cost for waste disposal which could be tolerated by processes having a 1:1 product-to-waste ratio. The possible exception is that a process already having a conversion cost of $2.00/Mg if operated at 2,000 Mgd might conceivably stand another 64¢ to dispose of the waste if it were 100 miles from the sea. Even this condition would involve a waste disposal cost equal to 30 per cent of the total cost. Processes such as the electrical membrane process which may have conversion costs of the order of 40-50¢/Mg from brackish water and a product-to-waste ratio of 4 or 5 will be in a better position on unit waste disposal costs. For example the 64¢ figure would be reduced to 12¢ per Mg of product. However, this still represents 20-26% of total product water cost.

For the majority of the conversion processes conveyance to the sea under eight original conditions would be prohibitively expensive even if the conveyance costs were reduced 50% which is approximately what happens if no power is used. Such a reduction would bring the 2000 Mgd-100 mile case to $.32 (for disposal alone), but none of the others would be reduced even to 50¢. To obtain low costs one must go to very high capacity as is shown in the bottom row listing a 100 mgd plant. Under these circumstances, still not a one of the distances has an associated cost less than 25¢ with the exception of the 100 mile case.

As a matter of fact even at 50 miles the 2000 Mgd capability does not reach 25¢. When this study was originally undertaken it was thought that plants located near the seacoast would not have a waste disposal problem since they could return their wastes directly to the sea by a short canal or pipelines. The above figures, however, indicate that the distance at which this becomes economic is considerably smaller than had previously been supposed. The distance becomes even less when one considers that in the average plant having a product-to-waste ratio of 1:1, two volumes of sea water must be transported to the plant for every volume of waste discharged, a total conveyance cost per unit of product equal to three times the above figures. For example, a 200 Mgd plant only 10 miles from the seacoast would still have a conveyance cost of over 50¢/Mg of product water.(Actually it would be about double this figure as shown in Table 4-3). Of course, plants so close to the seacoast could probably utilize canals, ditches and other cheaper waste conveyance methods since gravity flow would presumably be possible. The subject should be further investigated from that standpoint. On the other hand it is pointed out that even a plant located directly on the seacoast must still transport its waste for some distance in order to avoid contaminating its own intake.

The bird's-eye conclusions are:

a. Pipeline conveyance to the sea of conversion plant waste is economically prohibitive except at very large capacities and quite short distances from the sea.

b. Less than 15% of the western U. S. area within 500 miles of the sea or Great Salt Lake lies within 100 miles of these. Most of the waste conveyance to the sea will have to be for distances of over 100 miles.

c. That "seacoast" plants having by definition no problem in waste disposal must indeed be better described as littoral plants if they are to achieve economic waste disposal conveyance via pipeline.

CHAPTER 10

PROCESS II: EVAPORATE TO SATURATION AND CONVEY TO THE SEA

Synopsis - Mathematical Constructions - Disposal Costs - Critical Distances - Effect of Cheaper Evaporation

Synopsis Because the previous chapter showed that conveyance to the sea of the original waste was far too costly, this chapter studies the possibility that these costs of conveyance to the sea may be reduced by reducing the volume of waste to be transported by means of solar evaporation. If the difference between the cost of conveying the original waste and that of conveying the evaporated waste is greater than the cost of evaporating between the two concentrations, then the evaporation plus conveyance process will be more economic than straight conveyance.

Mathematical Constructions The cost of conveying waste at a rate Q_i Mgd is:

$$C_{CQ_i} \times d, \ \$/Mg$$

where

C_{CQ_i} = unit cost of conveying waste at rate Q_i, \$/Mg mi.

d = distance conveyed, mi.

The cost of conveying the evaporated waste per Mg of the original waste is given by

$$\frac{C_{CQ_2} \times Q_2 \times d}{Q_1}$$

where

Q_2 = amount of evaporated waste produced Mgd and

Q_1 = amount of original waste, Mgd.

The cost of evaporating original waste per Mg of original waste is:

$$\frac{C_{EQ_1^*} \times Q_1^*}{Q_1}$$

where

Q_1^* = amount of water evaporated from Q_1 Mgd of waste in going to Q_2 Mgd evaporated waste and

$C_{EQ_1^*}$ = unit cost of evaporating at capability Q_1^* , \$/Mg

Then the cost per Mg of Q_1 of evaporating Q_1 to a volume of Q_2 and conveying the Q_2 is:

$$C_{C+E} = C_{EQ_1^*} \times \frac{Q_1^*}{Q_1} + C_{CQ_2} \times \frac{Q_2}{Q_1} \times d, \text{ \$/Mg}$$

The parallel cost of conveying the original waste is

$$C_C = C_{CQ_1} \times d, \text{ \$/Mg}$$

letting:

$\frac{Q_2}{Q_1} = \frac{C_1}{C_2} = r$ ratio of initial concentration to final concentration, or of final volume to initial volume. (Density differences are neglected.)

Then:

$$C_{C+E} = (1-r)\ C_{EQ_1^*} + d\ r\ C_{CQ_2}, \text{ \$/Mg}$$

and

$$C_C = d\ C_{CQ_1}, \text{ \$/Mg}$$

Our problem is to find under what circumstances:

$$C_C > C_{C+E}$$

and what are the boundaries of this condition. It can be predicted that for very small values of d it will be cheaper to convey the original waste; at very large values of d, to evaporate first. Our problem is to determine the actual costs for the cheaper process.

The values of the expressions vary with the basic parameters E_t, tank evaporation "/yr and Q_1, volume of waste Mgd through their effect on the intermediate cost parameters.

Disposal Costs

That conveyance preceded by evaporation is indeed cheaper than conveyance alone in certain cases is shown by Figure 10-1 which has been calculated for 2000 Mgd and 40 inches evaporation, by means of the previous formulas using the basic parameters from the figures previously developed.

The ~~ordinate~~ Abscissa of this Figure is plotted in two quantities: r, the ratio of initial concentration to final concentration: and also C_1^* which is the concentration of an original waste from which evaporation to ratio r would produce a 260,000 ppm evaporated waste. For example, the waste having an initial concentration of 25,000 ppm cannot be concentrated to an r of less than about 0.1 otherwise crystals will precipitate from the then saturated concentrate. Actually, solids will be precipitating from some wastes possibly well before this point but the above statement is based on the arbitrary assumption that the salts involved are NaCl. Some care will have to be taken and some study will have to be given to the exact nature of each waste to avoid precipitation in and scaling of the pipeline through minor slightly soluble components of the waste which might pass out with the evaporating pond effluent in a super-saturated state. Because the problem depends on the exact nature of the waste it is not possible to attempt a solution in this study.

It is seen that at a 100 mile disposal haul a waste of about 26,000 ppm achieves a disposal cost as low as $0.44/Mg (under conditions of 2000 Mgd and 40 inches per year of evaporation), compared with $.64/Mg without evapotation. However this distance covers only 15 per cent of the land area considered in Chapter 9. To handle distances of 300 and 500 miles involves costs of $.90-1.30/Mg. Furthermore, conversion processes which reach high concentrations in the waste do not gain much advantage from evaporation.

If we consider a given original brackish water, conversion processes with a high product-to-waste ratio would reach higher concentrations in the waste than those with a lower ratio. Some degree of compensation for the unfavored processes in this regard is achieved through the fact that the favored processes then end up with a more concentrated waste and thus will suffer a higher disposal cost (in this disposal process) per Mg of waste.

Critical Distances for Evaporation

The question arises: How far does one have to be from the seacoast before it becomes economic to evaporate prior to conveyance? The critical distance is that at which:

$$C_C = C_{C+E}$$

It is given by:

$$d^* = \frac{(1-r)\ C_{EQ_1^*}}{C_{CQ_1} - rC_{CQ_2}}$$

where

d^* = critical distance beyond which evaporation plus conveyance becomes cheaper than conveyance alone, miles

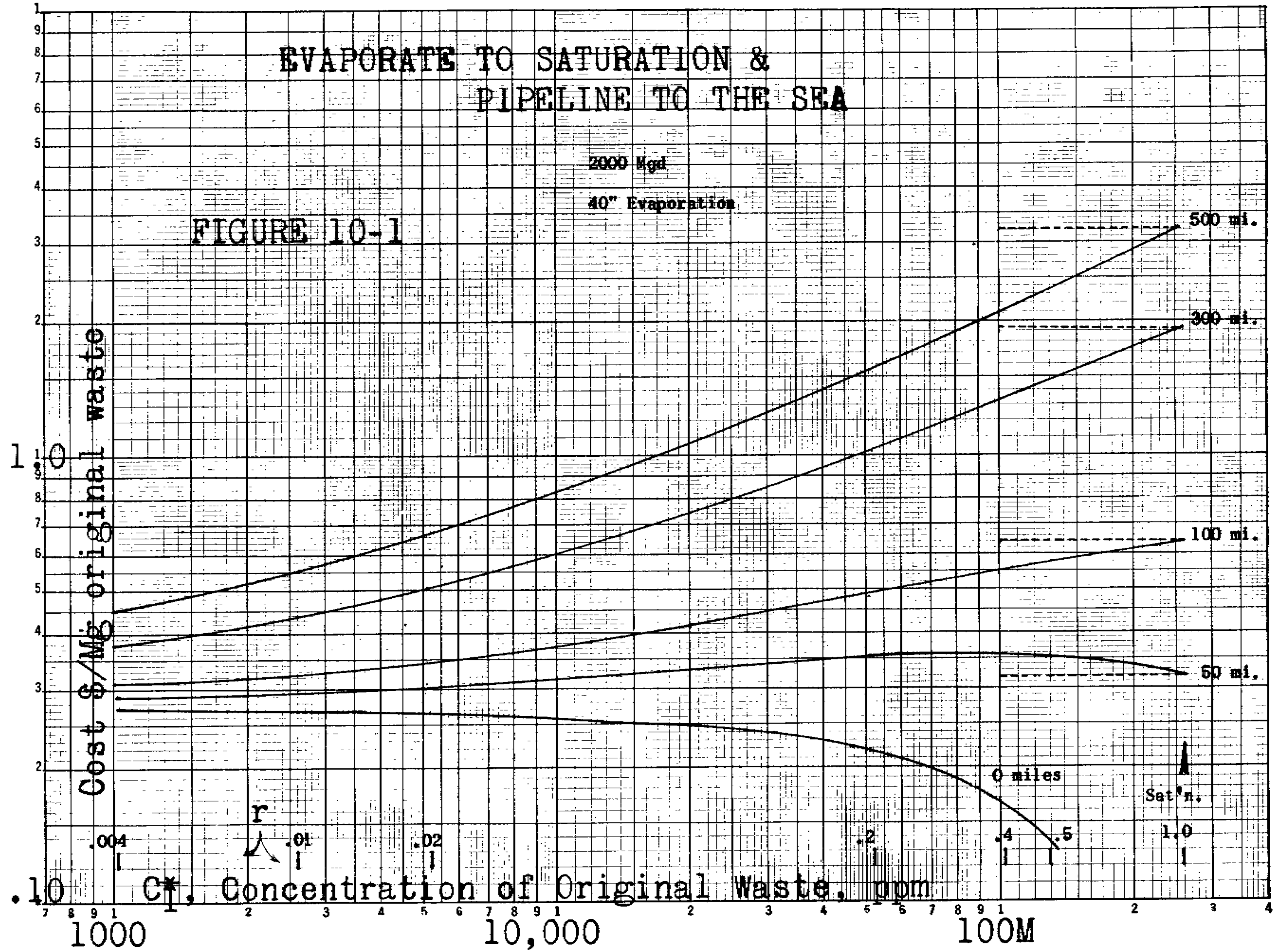

EVAPORATE TO SATURATION &
PIPELINE TO THE SEA
2000 Mgd
40" Evaporation
500 mi.
300 mi.
100 mi.
50 mi.
0 miles
Sat'n.
Cost $/Mg original waste
1.0
.10
r
.004
.01
.02
.2
.4
.5
1.0
C*. Concentration of Original Waste, ppm
1000
10,000
100M

FIGURE 10-1

The critical distance turns out to be rather insensitive for our purposes to the concentration of the original waste. For:

$$Q_1 = 2000 \text{ Mgd}$$

$$E_t = 40\text{", soil-cement}$$

it increases with C_I^* as follows:

C_I^*	2600	26,000	130,000	234,000	260,000
d*miles	50	53	69	77	∞

where C_I^* = concentration of original waste which is evaporated to saturation, ppm.

This calculation explains the 50 mile and 0 mile curves on Figure 10-1. It developed that, under the conditions chosen for Figure 10-1, 50 miles is below the critical distance and therefore evaporation followed by pipelining is more costly than direct pipelining over practically the entire concentration range. For a given value of C_I^* the critical distance decreases with E_t directly as $C_{EQ_I^*}$ does:

when

$$C_I^* = 26{,}000$$

$$Q_1 = 2000$$

E_t, inches	10	20	40	60	100
d*, miles	216	118	53	37	23

With capability it increases as follows:

when

$$E_t = 40\text{"}$$

$$r = 0.1$$

Q_1	20	2000	20,000
d*miles	7.5	53	157

The distance at which pipelining the original waste becomes economic over evaporating and pipelining becomes greater as: The evaporation rate decreases and the capability increases. It increases very slowly with concentration of original waste except when this approaches saturation.

Effect of Cheaper Evaporation

The curves of Figure 10-1 of course also vary with evaporation cost. The higher the cost of evaporation the less the advantage of using it. The effect on the curves would be to rotate them to lesser slopes (and curvatures) around their present positions at $r \approx 1.0$. Also the critical distance increases with increasing cost of evaporation.

Rough calculations have shown that if the evaporating cost could be reduced to a value approximating that achieved with an unlined evaporating tank the costs under the conditions of Figure 10-1 for a concentration of 2600 ppm would be reduced as follows:

Distance, miles	50	100	300	500
Soil-cement tank, \$/Mg	.30	.33	.44	.55
Unlined tank (approx.),\$/Mg	.05	.10	.20	.30

Also the critical distance would be much reduced in the example above from 50 miles to about seven miles. The conclusion is that it would be justified to give considerable study toward the objective of using unlined evaporation vats or otherwise decreasing the evaporation costs.

CHAPTER 11

PROCESS III: EVAPORATE TO DRYNESS AND CONVEY TO THE SEA

The previous chapters developed the economy of evaporating to saturation prior to pipelining to the sea. It is possible to evaporate beyond saturation completely to dryness and convey the resulting solids by freight. While at first it would seem unlikely that the cost of conveying solids by freight could compare with the cost of conveying the same solids as a saturated solution, and thus that the cost of the present process would be always greater than the cost of evaporating to saturation and pipelining, this turns out to be not the case.

The cost of this process is compounded of the cost of evaporating to dryness plus the cost of conveying the resulting solids. The latter as seen in Chapter 4 is

$$C_{Cs} = \frac{4.1725\ C_1}{10^6} \times (fd + 0.20), \text{ \$/Mg of original waste}$$

where

C_1 = ppm in original waste and

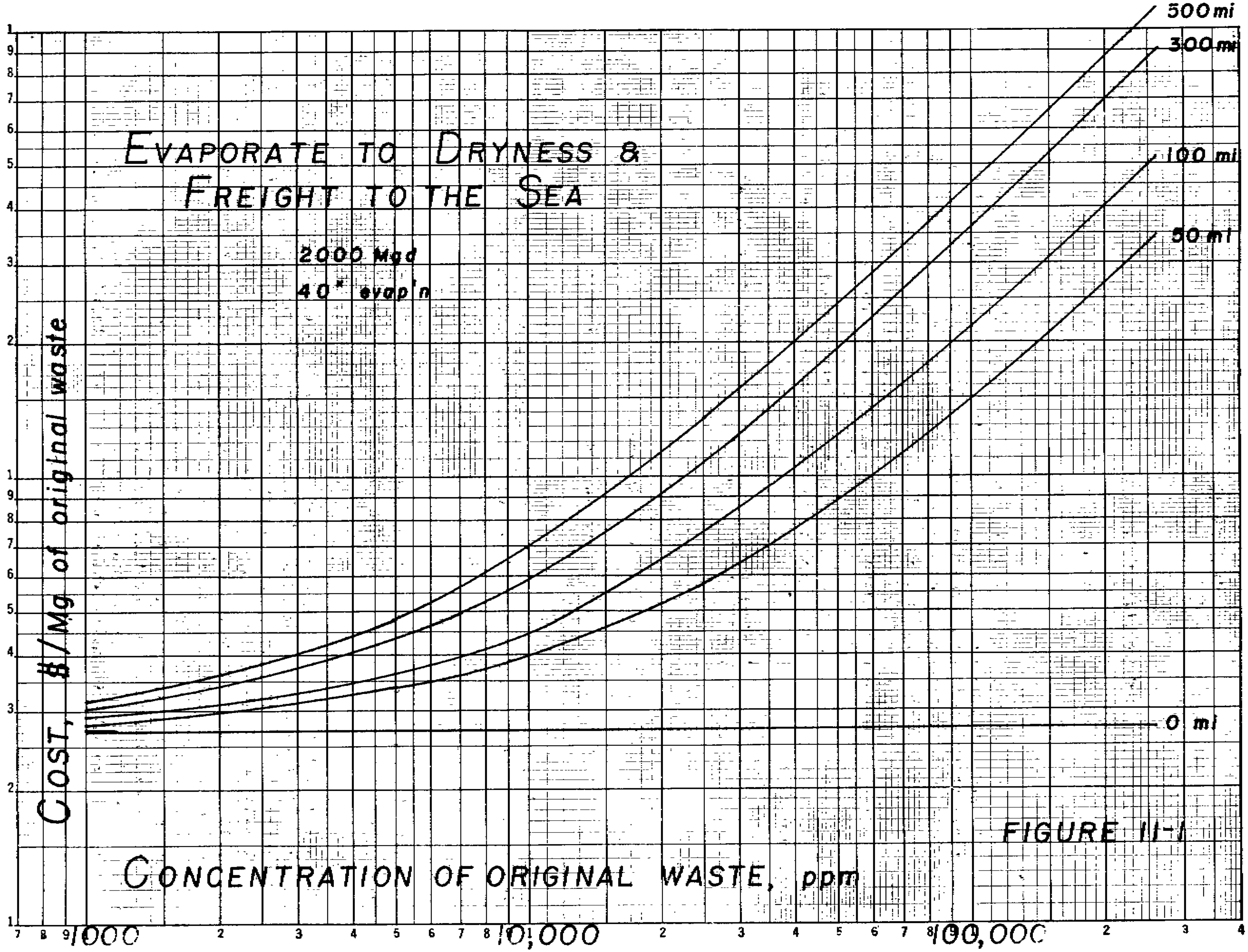
C_{Cs} = cost of conveying solids per Mg original waste, \$/Mg

The cost of evaporating has been developed in Chapter 5 and may be read from the Figure 5-2 there. The total cost of evaporating and conveying is therefore

$$C_{C+E} = C_{EQ_1} + C_{Cs}$$

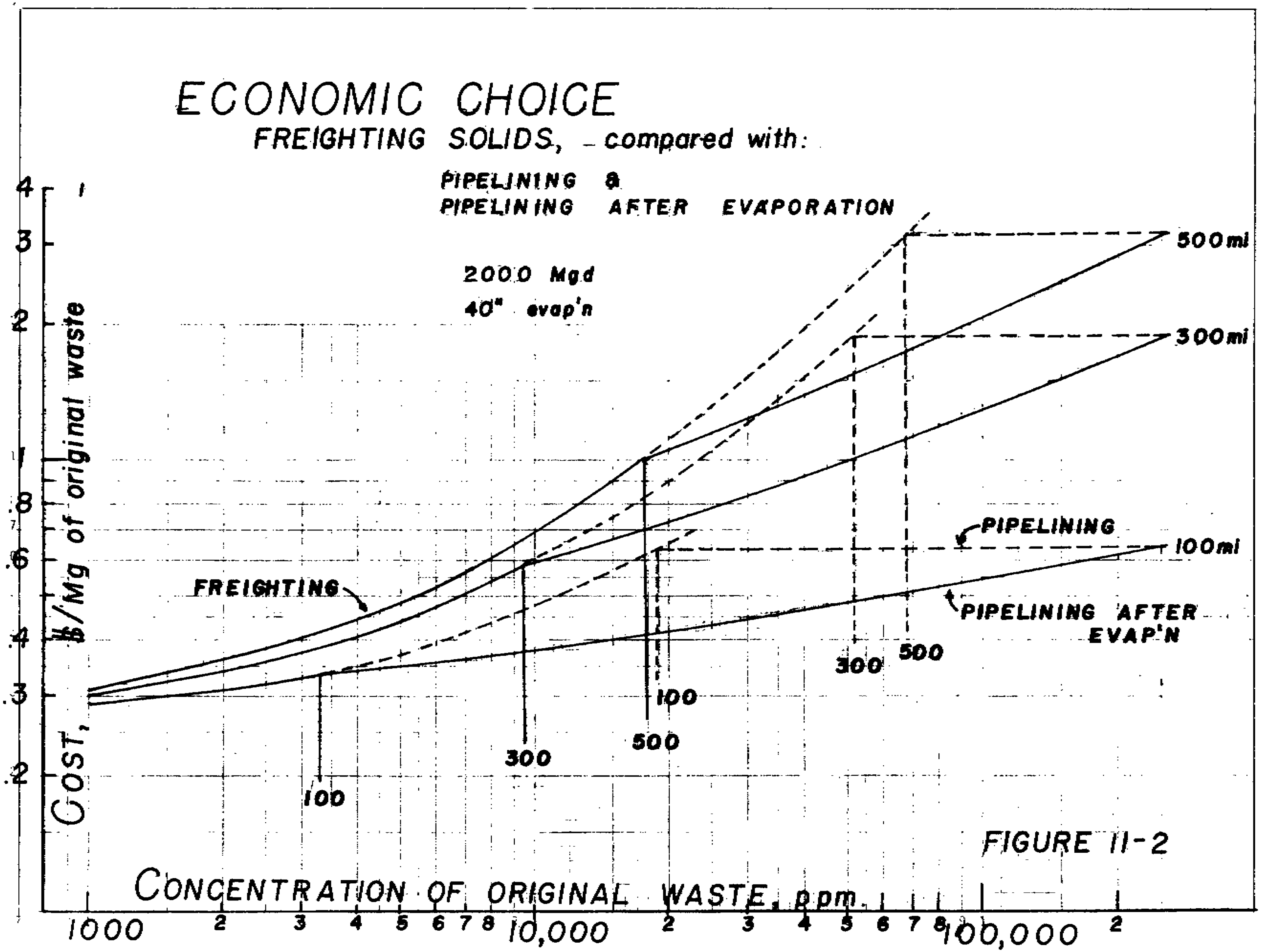
The cost of doing this for 40 inches evaporation and 2000 Mgd is shown in Figure 11-1. The 50 mile line is added for use in a later chapter.

It is instructive to compare the cost of evaporation to dryness and freighting with the competing processes of evaporation to saturation and pipelining, and of pipelining directly. This is done in Figure 11-2 which forms the basis for an economic choice. It is seen that at a 500 mile distance the freighting process is cheaper than pipelining after evaporation up to concentrations of original waste of about 18,000 ppm. Above that concentration it becomes cheaper to evaporate to saturation and pipeline. Above about 68,000 ppm (dotted lines) it becomes cheaper to pipeline the original waste than to evaporate it to dryness and freight it. The critical economic concentration between pipelining after evaporation and freighting after evaporation becomes lower as the distance becomes smaller. Nevertheless, since the main ranges of interest are 100-500 miles while the main concentrations are just about



EVAPORATE TO DRYNESS &
FREIGHT TO THE SEA
2000 Mgd
40" evap'n
500 mi
300 mi
100 mi
50 mi
0 mi
COST, $/Mg of original waste
CONCENTRATION OF ORIGINAL WASTE, ppm
1000
10,000
100,000

FIGURE 11-1


ECONOMIC CHOICE
FREIGHTING SOLIDS, - compared with:
PIPELINING &
PIPELINING AFTER EVAPORATION
2000 Mgd
40" evap'n
COST, $/Mg of original waste
CONCENTRATION OF ORIGINAL WASTE, ppm.
FREIGHTING
PIPELINING
PIPELINING AFTER EVAP'N
500 mi
300 mi
100 mi
100
300
500
100
500
300
500
1000
10,000
100,000
4
3
2
1
.8
.6
.4
.3
.2
FIGURE II-2

in the regions where the economic choices must be made, namely 3000-20,000 ppm, the matter becomes of considerable economic and competitive importance. If long distance conveyance turns out to be the cheapest disposal method then a more detailed study of this economic choice is thoroughly justified.

Some preliminary study has been given to the effect on these economic critical concentrations of changes in cost of evaporation. Evaporation affects both processes about equally, the more so at the low concentrations of interest. Accordingly, changes in it move both curves about the same amount and do not greatly alter the points of intersection. For example, a rough calculation has been made of the effect of lowering the cost of evaporating tanks down to the neighborhood of that of unlined tanks. The economic critical concentrations are almost unchanged.

CHAPTER 12

PROCESS IV: CONVEY AND LAND DUMP

Since the cost of conveyance is so high at reasonable distance from the sea, means may be soughtfor reducing these distances by seeking land areas as discussed in Chapter 7 which may be closer to the plant site. These distances may of course vary greatly and it might be arbitrarily guessed that they could not be closer than 25 miles to a center of population. 50 miles will be used here for illustration.

The cost is a simple sum of the cost for conveying 50 miles as already shown in Chapter 9 plus the operating cost of land dumping as developed in Chapter 7. The resulting values for 40 inches of evaporation are as follows:

TABLE 12-1

COST OF "CONVEY AND LAND DUMP", $/Mg
40" Evaporation
50 mile conveyance

Mgd	20	200	2000
Concentration, ppm			
1000	2.03	.917	.322
48,000	2.03	.917	.322
260,000	2.17	.949	.333
Without Dumping Cost	2.00	.910	.320

It is seen that the cost of land dumping is quite insignificant compared with the cost of conveying 50 miles and this insignificance does not change with evaporation rate. Conveyance and land dumping is practically equivalent in cost with conveyance alone.

The cost of conveyance and land dumping under the worst conditions of concentration for 25 miles would be about$1.09, $0.47 and $0.16 for 20, 200, and 2000 Mgd respectively. Conveyance of 25-30 miles breaks through the 25¢ level for the 2000 Mgd capability, but the practicality of this favorable situation depends upon the existence of 3640 acres of dumping grounds within 30 miles of the plant site.

Land dumping then is a device to cut down the conveyance cost by decreasing the conveying distance significantly below the distance to the sea.

CHAPTER 13

PROCESS V: EVAPORATE TO SATURATION AND CONVEY TO A LAND DUMP

Since conveyance is the major part of the cost of inland dumping even at 50 miles, further steps can be taken to reduce the conveyance cost. One of these is evaporation to saturation prior to conveyance and land dumping.

Figure 10-1 shows as a function of concentration of original waste the cost of evaporating to saturation and pipelining for 50 miles under conditions of 2000 Mgd and 40 inches evaporation. Figure 7-3 allows the calculation of the operating cost for land dumping as a function of concentration of waste dumped. We are concerned only with the operating cost per Mg of waste dumped at a concentration of 260,000 ppm which is the concentration of the conveyed liquor. The concentration of 2000 Mgd of original waste, (other standard conditions being 40 inches and 50 miles) results in a volume Q_2 of waste dumped equal to 2000 r where r is the ratio of the original concentration to the saturation concentration 260,000 ppm. This operation produces volumes of waste dumped (corresponding to various concentrations of original waste) which are not directly determinable from Figure 7-3. However, an interpolation curve for the three capabilities allows an accurate estimate at the intermediate capabilities. These costs, $/gpd of waste dumped, must still be multiplied by r to obtain $/gpd of original waste.

When all this is done it is found that the operating cost (0.178 x $/gpd) of land dumping of saturated liquor per Mg of original waste varies from $0.0015 to $0.013/Mg depending on the concentration. These add only 3% at the most to the cost of evaporation to saturation followed by pipelining 50 miles as shown on Figure 10-1. Accordingly the cost of evaporating to saturation and conveying to a land dump is insignificantly different from the cost of evaporation to saturation and pipelining the same distance to the sea.

But Figure 10-1 shows that there is no advantage in evaporating prior to pipelining when the distance, as taken in this case, is only 50 miles, for this is below the critical distance as developed in that chapter, for the conditions (2000 Mgd and 40 inches evaporation). While all the values of the parameters have not been explored Chapter 10 shows that 50 miles or more is the critical distance for all conditions explored except those of very high evaporation (60-100 inches) or very high capabilities (over 2000 Mgd). Therefore, in general it may be stated that in the use of land dumps within 50 miles there is usually no advantage to evaporation prior to pipelining.

If the cost of evaporating can be reduced evaporating prior to land dumping might become economic, but only to the extent that evaporating can reduce the cost of conveying -- i.e. only to the extent that a lower cost of evaporation can reduce the critical distance.

The practicality of the land dump approach remains in the availability of suitable land dumps within 25-50 miles of proposed plant sites. It is recommended that a study be undertaken of the existence and geographical distribution of land dump sites. This study should result in information similar to that in Figure 9-1 and Table 9-1 on the distribution by distance from the sea. The land dump study however would be more complicated because the location of suitable sites is not demarked as is the sea coast on a map, the suitability of the site must be reconnoitered in the field, and the capacity of the land dump must also be determined.

CHAPTER 14

PROCESS VI: EVAPORATE TO DRYNESS AND CONVEY TO A LAND DUMP

The cost of land dumping solids is shown in Table 7-2. For most concentrations it is even less than the cost of land dumping liquids. The cost of evaporating to dryness and freighting 50 miles to the sea is shown in Figure 11-1. The cost of the combination of these is the simple sum which is insignificantly different from the cost of the latter, as shown in Table 14-1

TABLE 14-1

OPERATING COST OF: EVAPORATE TO DRYNESS,
2000 Mgd, 40", FREIGHT 50 miles
LAND DUMP, 10 ft./century

Conc. original waste	1000	100,000	260,000
Cost $/Mg	.0476	1.265	3.22
Cost, ex. land dump	.047	1.26	3.21

The principles of critical distance and economic choice as worked out in Chapters 11 and 13, while not illustrated in Figures for this case, lead to the conclusion that up to concentrations of about 3500 ppm evaporation to dryness and freighting is cheaper than the next best method which is direct pipelining to a land dump. Because of critical distance considerations, the cost of evaporation to saturation and pipelining is greater than either of these. The economy of freighting solids over direct pipelining is very small in the narrow range of concentrations where it occurs while the economy of direct pipelining over evaporation to dryness and freighting is very large at the higher concentrations where it occurs. This may be visualized by drawing a horizontal line at $0.32/Mg on Figure 11-1 representing the cost of direct pipelining 50 miles.

Again, a substantial reduction in the cost of evaporation, say by the use of unlined tanks would lower the cost of this freighting process and increase the critical economic concentration at which direct pipelining becomes favored.

CHAPTER 15

PROCESS VII: ABANDON

There is little to the process itself that has not already been discussed under the operation in Chapter 7. As discussed there for the 2000 Mgd, 40 inch evaporation case, the cost varies from 32¢ to $1.95 per Mg depending on the concentration of the original waste, and remains at 32¢ up to quite high concentrations.

The major cost of abandonment lies in the heavy investment required for concrete tanks to contain the material indefinitely near populated areas. None of the major parameters except evaporation rate can be looked to to lower the cost. Possibly an area suitable for land dumping might be found within a very short distance of a plant site. This would be the equivalent of land dumping at practically zero conveyance distance, also of abandonment without the cost of concrete structures. Under these circumstances the cost of abandonment or land dumping, which here merge into one, would be extremely low. It would be in the range of $.00238 to $.0129 Mg depending on the concentration. It is not known how general may be the existence of such sites.

The practicality of this process depends upon the existence of rather large tracts of land which can be permanently abandoned, quite close to a point of potential water use, i. e. quite close to a populated community. This brings up a rather odd situation in land economics. Consider two types of locations in the arid and semi-arid lands. One type is a location which has some fresh water. The land near this location thus has some value and a community springs up around it which further increases land values. The other type consists of a barren and useless wasteland such as an alkali flat or the like. Both types have supplies of brackish water which could be converted to fresh water.

If abandonment should turn out to be the preferred disposal process, the wasteland rather than the existing community would be preferred as a plant site. For the land around the existing community, if only by association, would have a rather high value and thus there would exist a barrier to its use for abandoning operations. The wasteland rather would be the favored site for a brackish water conversion plant. The tendency therefore in any general introduction of brackish water conversion plants would be to utilize these portions now considered the most useless. Thus under the exceptional circumstances the effects of brackish water conversion would be in opposition to almost all other civilizing and industrializing forces, namely to bring about a decentralization of civilization and industry rather than a centralization around already existing centers.

While the availability of worthless land thus becomes an asset (and the more worthless it is the greater the asset) yet any wasteland Chamber of Commerce which espoused this cause would find it self-defeating since the bringing of water to the location through brackish water conversion would automatically supply the pressure to increase land values and thus destroy the asset. It is apparent therefore that in this situation technology must move in first prior to civilization and develop a water supply and an abandonment ground before the economic forces have been set in motion.

But except in the rare form of land dumping at the plant site abandonment is not likely to become a favored disposal method and thus only a very few Chambers of Commerce of the next generation would be faced by such an "agonizing appraisal".

CHAPTER 16

PROCESS VIII: INJECT

This process consists simply of applying the injection operation at the plant site. The cost is the same as the injection operation cost as shown in Figure 6-4 for it has been assumed that no prior treatment will be required. Possibly some storage ahead of injection would be indicated in order to take care of periods of well or pump shut down. A standby pump might have been provided for the pump emergency. Storage might equally well be indicated in the Processes I and IV involving direct conveyance. But it would not be required with the processes involving evaporation at the plant site since the ponds themselves would provide the necessary storage. However, storage is a matter which has been left for a more detailed study. It is seen that the cost of injection at least in the high capabilities used generally for illustration is well below the cost of other methods considered up to this point, which for 2000 Mgd have a minimum cost of about $.28/Mg at low concentrations increasing at higher concentrations. If one is fortunate enough to find a suitable formation at a depth of 4000' which is probably about the minimum that could be tolerated for large scale injection, and if the reservoir conditions are such as to allow gravity operation, a low cost of about $.0061/Mg could be achieved. At a median casing head pressure this cost would be about $.036 and at a pressure approaching the highest encountered would rise to only $.10. Even in the worst case of 12,000 feet and 900 psi pressure the disposal cost would be only $.126/Mg, still well below the minimum for the other processes heretofore considered.

While very gratifying this is not an indication that injection is the solution to all disposal problems. Successful injection depends upon the favorable condition of finding a formation to inject into. These do not automatically exist everywhere. Furthermore, exploring for one may involve a considerable amount of money. In oil well drilling, for example, in unproven territory seven wells are drilled in order to find one producer. Even in established and producing fields one well out of four drilled turns out to be unproductive. (16-1) If this is the situation with over 600,000 producing oil wells probing the known formations, it is quite unlikely that 100% success ratio can be achieved in drilling injection wells and searching for injection formations. Even after a successful well is drilled the possibility exists of unpredictable variations in its injection capability. While evaporation for example also has some variability, it is subject to statistical prediction to a degree to which the art of injection has not yet attained.

It is interesting to note that a study similar to the present one conducted over a quarter of a century ago also reached the conclusion that injection was the preferred method of disposal. The unpublished document reporting that investigation has not yet been located but a reference to it is made in still another unpublished document (6-3) as follows:

"Early in 1931 the East Texas Anti-pollution Committee prepared a very comprehensive report on the following methodsof salt water disposal:

1. Discharge to natural drainage
2. Storage and controlled discharge into natural drainage
3. Injection into Woodbine sand
4. Solar evaporation
5. Mechanical evaporation
6. Canal to tidal water
7. Pipeline to tide water"

The above list covers many of the alternatives that are studied in the present work and two that are not - mechanical evaporation and canal to tide water. The search for the 1931 report is being continued.

REFERENCES

(16-1) Common drilling statistics, e. g. Oil & Gas Journal, January 7, 1957. p 187.

CHAPTER 17

PROCESS IX: EVAPORATE AND INJECT

The cost of injection per Mg injected does not increase ten fold as the capability decreases ten fold. Accordingly, it costs less per Mg of original waste to inject an evaporated residue, specifically a saturated residue from evaporation of that waste. Calculation shows however, for the conditions 6,000' depth 260 psi, 2,000 Mgd, 40 inches evaporation in soil-cement tanks that the cost of the necessary evaporation much more than balances the saving in injection so that the total cost of the process for all concentrations per Mg of original waste is greater than the injection cost of the original waste itself. For example, it costs $.270/Mg to evaporate 2,000 Mgd of 5200 ppm to saturation, a volume of 40 Mgd. Then it costs only $.008/original Mg to inject the residue -- a total of $.278. But it only costs $.039 to inject the 2,000 Mgd in the first place. Thus no saving can be achieved by this process.

While the above is calculated for only one set of conditions it is quite likely that it holds true over a considerable range. It would be least likely to hold true when unlined tanks can be used and evaporation rate is high. Similar simple observations cannot be made for the injection parameters because the relation between the costs of injection at two capabilities is a very complex function of the injection parameters, including the capabilities.

CHAPTER 18

PROCESS X: CONVEY AND INJECT

Using Old Wells

The price of an injection well is rather high and the country is dotted with abandoned oil wells which might seem attractive for use as injection wells thus eliminating the cost of a new well. Except in the highly unlikely possibility that an abandoned oil well would be at the conversion plant site this process would involve conveyance of the waste to the given location of the abandoned well.

In the business of disposal of salt water from oil fields the use of abandoned wells is not looked on with great favor. An injection well is a specialized device which, it is said, cannot well be made over out of an old oil well. Furthermore, to do so is not inexpensive. The average cost of converting six old oil wells in the East Texas Field in 1944-5 was $19,500 (ENR = 650) not including the cost of new cement-lined tubing then being used. At 3700' depth this comes to $5.37/ft. (6-1)

Reference (6-5) states that the expense of drilling an old well deeper to rehabilitate it frequently is almost as much as the cost of drilling a new well. In advocating acidizing and good maintenance it is there indicated that the cost (in 1951) of pulling tubing from an old well and cleaning it out with cable tools might be $4,000-5,000 which in the 3400' wells under discussion amounts to at least $1.42/ft. (ENR = 650).

Assuming however that an old well was reconverted at a cost the average of the above two namely $3.35/ft., the resulting savings in injection costs for a 6,000' well at 260 psi and 2000 Mgd would be $.00435/Mg. However, conveyance of this quantity as shown on Figure 4-5 costs $.0064/Mg mile. This means that to just break even on the above scheme one would have to be fortunate enough to find an abandoned well within three-quarters of a mile of the plant site. Even in the most favorable case, that of a 12,000' well, the old oil well would have to be within two miles of the plant site.

In other words, under these conditions conveyance is so much more expensive than injection that the saving by use of an abandoned well is soon eaten up in conveyance costs.

At 20 Mgd and 6000' the picture is a little more favorable, the break-even point being at about 10 miles. This is not to be taken too literally however, for as shown in Table 4-3 a considerable correction factor must be applied to our conveyance figures when they are used for such short distances.

Without working out every case in detail it appears quite unlikely that any general benefit can be looked for in the use of abandoned oil wells as injection wells except in the rare instances where one happens to exist on the plant site.

Effect of Conveyance

While conveyance to make use of an abandoned oil well is not very attractive it is quite conceiveable that a process may be forced to conveyance for lack of an injection well site on the plant grounds. If it is necessary to convey the waste to a nearby injection site the conveyance costs rapidly become a major share of the total cost. The following table shows this. It is calculated on the basis of 2000 Mgd and applying the cost increases for short hauls as obtained from Table 4-3. (Note that this is the only place in this report where the short haul correction is made).

TABLE -1

Miles	0	2	5	10	20	50
Cost of Conveyance and Injection $/Mg	.038	.076	.118	.166	.242	.483

The advantages of injection are soon lost if it is necessary to convey even a short distance.

CHAPTER 19

PROCESS XI: EVAPORATE TO SATURATION, CONVEY, AND INJECT

This chapter was originally intended to cover the possibility that though neither use of an abandoned oil well nor evaporation prior to injection when used singly could reduce the cost of injection, yet possibly both together might do so. However, in the previous two chapters it has been shown that conveyance will cost more than the saving in injection, and evaporation will also. Needless to say therefore, it is arithmetically impossible that both together can reduce the cost since either the conveyance or the evaporation must be done on the original amount of waste.

CHAPTER 20

PROCESS XII: DISCHARGE TO FLOODING STREAMS

Total Potential - Upstream Reservoirs - Downstream Reservoirs - Legal Problems

The technical operation and the cost thereof have been developed in Chapter 8. However, there are many ramifications of a policy nature between the operation and the process. The setting of the ultimate social policy governing discharge of saline water conversion wastes to streams is something that will certainly take many years of social and political action. Some salient points however may be brought out here as a guide to policy.

Total Potential In the first place it should be pointed out that the total capacity for assimilating waste salts is possibly not very great. Our example showed that the Canadian River at Amarillo might assimilate in its flood flow the equivalent of one good sized water conversion plant at Amarillo. It could not assimilate the wastes from another such plant until the additional flood flow from drainage area downstream has built up a volume of flood flow equal to that appearing at Amarillo. The drainage area above Amarillo is 19,287 square miles. An additional 19,000 is not added to the Canadian River drainage area prior to the entrance of the North Canadian at Wetumka, Oklahoma. However, the runoff is probably higher as one travels downstream (east). The flow of the Canadian River in 1952 did not reach double the flow at Amarillo until somewhere between Bridgeport, Oklahoma and a point just above the entrance of the Little River near Calvin, Oklahoma where the flow was about three times that at Amarillo. Bridgeport is about 200 airline miles from the Canadian River at Amarillo and Calvin about 340 miles. As a matter of fact, the flow at Bridgeport was less than at Amarillo and the concentration was about the same. Assuming that the flooding characteristics correspond with the average daily flow, wastes from another saline water conversion plant could not be discharged into the Canadian River until at least 200 miles from the one at Amarillo. If this should be typical of the entire arid region (a subject which has not at all been explored herein) it would mean that such waste discharging operations might be limited to one for each several thousand square miles of territory. Nevertheless, discharge to flooding streams is one of the cheapest disposal methods and therefore should be considered further, especially if a more detailed analysis shows that the process is of more general application than on the Canadian River.

Upstream Reservoirs One of the criteria of interest is the existence of upstream or downstream dams for storage purposes. If there is an upstream dam for containment of flood flows, then presumably there will be a regulated release and no flood flows will pass the disposal site. If there were no evaporation from the upstream dam the concentration passing the disposal site would be the weighted average concentration without the dam. This would be lower than the average "normal" concentration and the stream would have the same capability for assimilating salts as without the dam.

In fact, under these circumstances it would be possible to eliminate the waste storage because waste could be discharged into the river every day rather than waiting for flood flows.

Evaporation from the dam however, especially in arid regions, and from the ever-normal river, might be enough to raise the average concentration of the released water higher than the "normal" concentration. In that case the rationale of the proposed system for determining pollution limits falls down and it becomes a question of how much more salt load the river can stand and who is responsible for it -- the dam or the conversion plant.

Downstream Reservoirs The question of downstream storage reservoirs is even more interesting. Consider the case where the brackish water being converted is taken from the river into which the wastes are to be discharged. This means that all the salts which are returned to the river in the waste were originally present in the river. No change has been made except that a certain amount of water has been extracted from the river thus concentrating somewhat the salts present. The average flow of the Canadian River at Amarillo in the years shown in Figure 8-1 is about 150 cfs corresponding to about 100,000 Mgd. Thus the largest plant under consideration, 2,000 Mgd, would increase the salt content by only a few per cent if the plant feed were taken from the river. A delicate point thus arises, which probably could and will be argued in much greater detail, namely does taking pure water out of a river constitute pollution? It should be pointed out (20-1) that doing this is no different from damming up and using the water of a fresh water tributary to a brackish water stream. Such a dam removes water from the brackish river or rather prevents its mixing with the brackish river, and results in the same end point as saline water conversion from the river water.

In any event the system of discharging wastes from river water conversion plants will result in higher concentrations in the downstream reservoir. The amount of increase in concentration depends on the relative capabilities of the plant and the river and the importance of the increase in concentration depends on the increase resulting from evaporation in the downstream reservoir. In our Canadian River examples the downstream river had an average of 1170 ppm compared with its undisturbed average of about 700 ppm.

Effects of a different order of magnitude occur when it is proposed to convert brackish ground water or brackish water from sources other than the river and discharge the resulting wastes into the river. In this case the total amount of salts in the river is increased in the absolute sense as well as in concentration. This is the case for which the operation in Chapter 8 was calculated. As there indicated, some reasonable limit may be chosen for concentration and the stream can assimilate a certain amount of added salts within that limit. However, if there is a downstream storage reservoir, then serious trouble may arise from the added salts. For example, some cities taking water from reservoirs in arid regions have to resort to softening. The effect of an upstream saline water conversion plant discharging a hardness constituent into the river would be to increase the softening costs for the downstream municipal supply. Presumably the increase in costs would be a reasonable charge against the plant operation.

Legal Problems The whole problem of disposal to flooding streams is complicated not only by the technical factors but also by legal matters, property rights, water rights, and the attitudes of the numerous local enforcement agencies. Initially in this study it was intended to explore some of the legal aspects of especially this process. The attempt was abandoned for the following reasons:

a. It is very difficult to obtain opinions from the enforcement agencies concerning events which have not yet happened.

b. Many pollution control laws and concepts concerning the limits of pollution are in a state of flux.

c. The problem, if it becomes anything but a quite local problem, is of such importance and magnitude that some basic philosophies of pollution and anti-pollution may have to be changed to accomodate it. Stated directly, this means that in semi-arid regions mankind may have the choice between fresh water in the rivers and no water in the reservoirs, or fresh water in the reservoirs and salt water in the rivers.

This study has shown that discharge to flooding streams promised to be a low cost method of disposal. It is lower than any other method except injection and lower than injection methods except at high capabilities and low horsepower requirements. These judgements are only preliminary and semi-quantitative but they are an indication that discharge to flooding streams must be given serious consideration as a disposal means despite the pollution problems which it generates. The projections of this study reach into the next century. While pollution may be a sin against nature, uselessness is also a sin against nature and within the next century some general compromise between the two must be reached.

* * * * * * * * * * * * * * * * *

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(20-1) Ferris, T. C. - personal communication.

CHAPTER 21

USEFUL BY-PRODUCTS

While relegated to the final chapter, the first thought that comes to mind, especially to the layman, in considering disposal of saline water conversion wastes or any other wastes is whether the waste material cannot be developed into a useful by-product. This idea is particularly prominent in saline water conversion waste thinking because the wastes are not the noxious substances ordinarily in that category but are rather simple mineral salts to which in other forms some value attaches.

The subject has been relegated to the final chapter in this study because essentially it is not a part of the study. If it is possible to take some of the saline water conversion wastes and process them further in some way to yield useful products then this operation is no longer part of the waste disposal problem but becomes part of the manufacturing process itself. Resulting from that manufacturing process there may or may not be the ultimate waste for disposal. It is only the disposal of this final waste which is considered in the present study. Investigation of the utilization of the original waste involves entirely new problems.

Nevertheless, some utilization method which took all of the primary waste would indeed completely eliminate the ultimate waste disposal problem. Secondly, while major attention up to the present has been concentrated on economic saline water conversion process it is possible that some useful by-product from the primary waste might also yield a profit thus reducing the net cost of waste disposal, and allowing the use of some disposal methods now out of economic reach, or allowing the placement of saline water conversion plants in locations not economic otherwise. In these senses the problems of waste utilization and waste disposal impinge on one another.

Finally, it may so happen that one of the operations used in the ultimate waste disposal process may put the waste material in a form more suitable for by-product utilization. In this aspect the two problems definitely intermesh and this is the only aspect considered in the present study.

Attention therefore is particularly directed to those materials which are now extracted from brines, saline waters or sea waters. Among these are magnesium, bromine, iodine, chlorine, sodium carbonate, sodium hydroxide, sodium sulfate, borax, potash salts and a number of others. Where a more concentrated form of the raw materials for these substances is of advantage in the process there may be some economic benefit in utilizing saline water conversion wastes.

As described earlier, most saline water conversion processes do not greatly concentrate the feed material. Most of the processes seem to be limited to a doubling of the concentration: one of them is apparently economic at a five or six fold increase. Throughout this report it has been generally assumed for calculating purposes that the salts in the brackish water are sodium chloride alone. However, of course, there is a great variation in the composition of dissolved solids in natural waters.

Off hand, without the more serious study which probably should be given the subject, it would appear that little advantage is to be gained, by the concentration factor available from saline water conversion processes themselves in the production of the heavy chemicals ordinarily obtained from saline brines. For, from brackish waters, the concentration of total dissolved solids cannot be expected to rise beyond maybe five or six per cent. The brines used for heavy chemical production (sodium carbonate, sodium sulfate, potash, borax, etc.) are among the cheapest chemical raw materials and are readily available in concentrations up to saturation of 25-35 per cent. It therefore appears likely that establishment of a plant to process the relatively weak waste brines of saline water conversion plants for heavy chemicals would be quite uneconomic.

Of more interest would be the utilization for heavy chemical production of the saturated brine produced by those processes of this report involving evaporation to saturation. Such a utilization if economic would add an additional advantage to the processes involving evaporation to saturation in that credit could be taken for the by-product. Without considerable further study of specific instances the general economic possibilities cannot be stated. The first thing that comes to mind is that the saturated brines so produced contain a variety of constituents other than the one probably desired for manufacturing. Purification of the typical saline water conversion evaporated waste to yield a quite pure saturated NaCl solution such as is needed for chlorine and caustic manufacture would probably be economically prohibitive. Similarly the removal from the average natural water of scaling constituents (especially Ca and Mg) such as has already been accomplished by nature in the saline deposits of the arid west would also probably be uneconomic. Nevertheless, the subject might be worthy of investigation by the interested parties.

Of more interest is the possibility of recovering some of the minor constituents from the solar evaporated brines. Such brines are more amenable to this exploitation for two reasons:

a. The conventional raw materials for these minor constituents such as bromine, iodine, magnesium already are highly "contaminated" with other saline materials and thus the present processes are more on an economic equality with that which would be used for treating the conversion brines.

b. Not a small part of the costs of extracting these minor materials comes through the necessity for handling tremendous quantities of brine. The extraction of magnesium, for example, involves the handling of at least 800 tons of sea water per ton of magnesium produced. Extraction of bromine involves handling at least 16,000 tons of sea water per ton of bromine.

As raw materials for these minor elements it might be advantageous to utilize evaporated conversion plant wastes which might concentrate the solids as much as a hundred fold. Iodine extraction may be taken as an illustrative case. Initial extraction of iodine from oil field brines in this country was in Louisiana where the brine contained about 35 ppm. Iodine is now extracted from California oil field brines having concentrations of up to 75 ppm (21-1). The iodine content of the California brines appears to have no relationship to the sodium chloride content which is about the same as that of sea water. If brines of this quality were used in the saline water conversion process for the manufacture of water and then the wastes were evaporated to saturation of the major constituent, the potential concentration of iodine would be around 700 ppm. It is quite likely such a brine would be an economic raw material for iodine manufacture.

But, while this might be fine for iodine manufacture, it would be of little importance for saline water conversion waste disposal. The total quantity of iodine consumed in the United States is in the neighborhood of two million pounds per year. This much iodine is annually present in about 10,000 Mgd of a 70 ppm feed water. This means that less than 3 typical (1:1 product-to-waste ratio) plants of the highest capacity considered in this study (2,000 Mgd) would be able to saturate the national market with iodine if they operated on a feed containing 70 ppm I. While the profits from iodine sales might help the waste disposal or water conversion picture in a few plants it could not under present circumstances be any solution for the general problem.

The same sort of arithmetic applies to the manufacture of other chemicals including heavy chemicals from the waste brines. For example, the current consumption of chlorine in the United States is something of the order of two million tons per year. This amount of chlorine could be obtained from the wastes of conversion plants supplying a city of 760,000 people from a 10,000 ppm NaCl feed at the average western municipal and industrial consumption of 287 gallons per capita per day. This means that supplying the water for a city of less than a million people would supply all the chlorine for the remaining 159 million.

For these reasons, although it is highly recommended that the subject be studied further especially for the promotion of the first commercial water converting plants it is obvious that by-product utilization is not the general solution to the waste disposal problem per se.

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REFERENCES

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